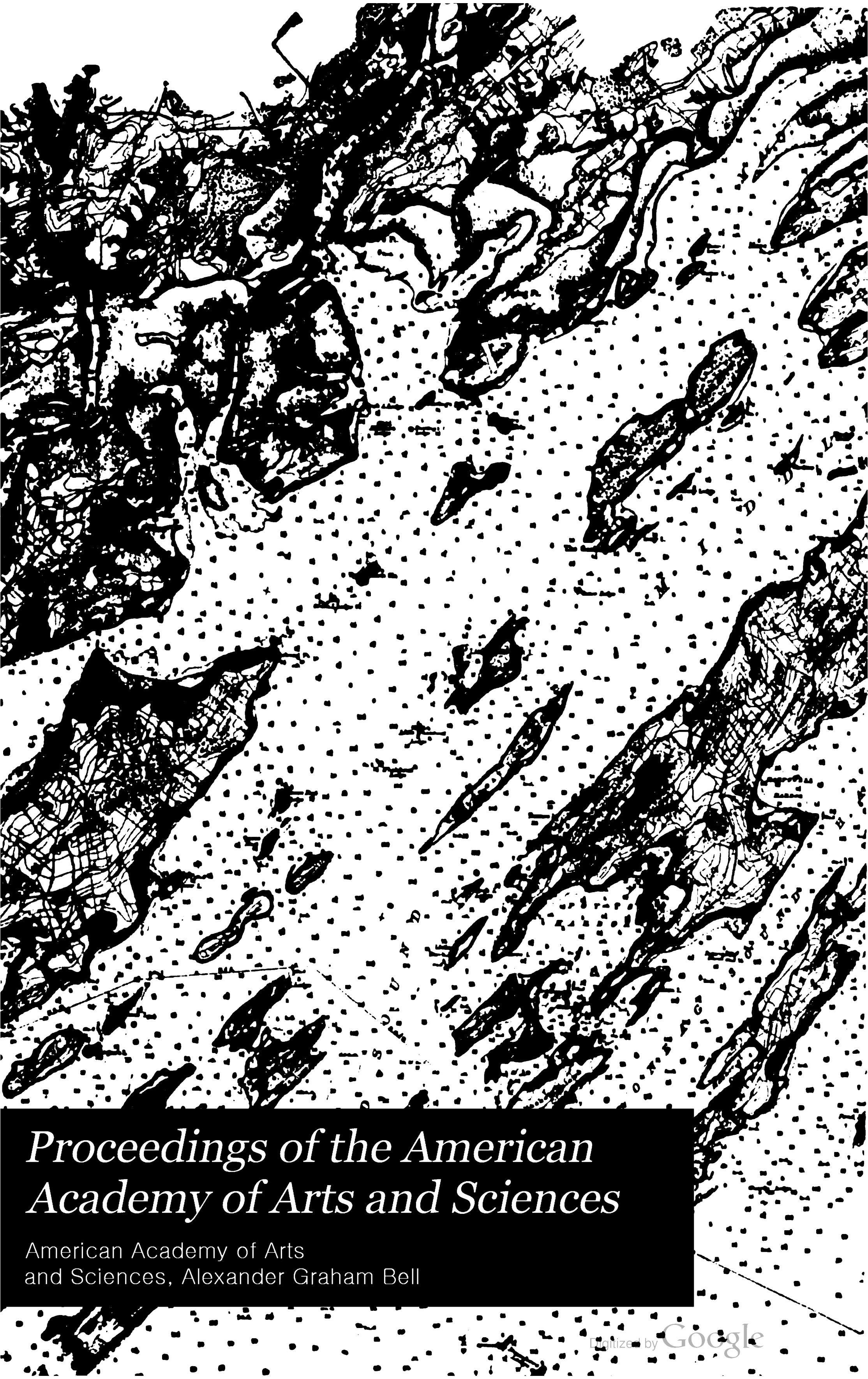

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ON THE THERMAL CONDUCTIVITIES OF CERTAIN POOR CONDUCTORS. — I.

By B. O. Peirce and R. W. Willson.

Investigations on Light and Heat, made and published wholly or in part with Appropriation from the Rumford Fund.

ON THE THERMAL CONDUCTIVITIES OF CERTAIN POOR CONDUCTORS. — I.

BY B. O. PEIRCE AND R. W. WILLSON.

Presented April 13, 1898.

WE have been engaged for several years in an attempt to measure, by the aid of the so called "Wall Method," the thermal conductivities of certain relatively poor conductors,* and the variations of these conductivities with the temperature. We have at length succeeded in overcoming some of the difficulties which we have encountered, and are now ready to describe our apparatus and to give the results of a number of observations made with it.

When one end of a regular right prism of $2n$ sides made of homogeneous material is kept at a constant temperature, V_0, and the other end at a constant temperature, V_l, while its other faces are kept as nearly as possible at some constant temperature between V_0 and V_l, the temperatures on the axis of the prism in its final state depend very largely on the ratio of the length of the axis of the prism to that of a diagonal of a cross

* Despretz, Ann. de Chimie et de Physique, 1827. Peclet, Ann. de Chimie et de Physique, 1841. Tyndall, Phil. Mag., 1853. Hopkins, Phil. Trans., 1857. Pfaff, Pogg. Ann., CXIII., 1861. J. D. Forbes, Proc. Edin. Soc., IV. Ångström, Pogg. Ann., CXIV., 1861. Neumann, Ann. de Chimie et de Physique, 1862. G. Forbes, Proc. Edin. Soc., VIII., 1873. Herschell, Lebour, and Dunn, Rep. Brit. Assoc., 1873. v. Beetz, Pogg. Ann. Jubelband, 1874. Smith and Knott, Proc. Edin. Soc., 1875. Lodge, Phil. Mag. 1878. Less, Journ. de Phys., VII., 1878. Ayrton and Perry, Phil. Mag., 1878. H. F. Weber, Vierteljahrschrift d. Züricher Naturf. Ges., 1879. Thoulet, Comptes Rendus, 1882. Lagarde, Comptes Rendus, 1882. v. Littrow, Wien. Ber., LXXI. Stefan, Carl's Rep., XIII. Jannettaz, Comptes Rendus, 1884. Tuchschmid, Beiblätter z. Wied. Ann., 1884. M. Ballo, Dingler's Journ., 1886. H. Meyer, Wied. Ann., 1888. K. Jamagawa, Beiblätter z. Wied. Ann., 1889. G. Stadler, Inaug. Diss., Berne, 1889. Venske, Göttinger Nachrichten, 1891. Grassi, Atti Ist. Napoli, 1892. Lees, Phil. Trans., 1892. R. Weber, Bull. Soc. Science Nat. Neuch., 1895. Lord Kelvin and Mr. Murray, Proc. Royal Soc., 1895. Peirce and Willson, American Journal of Science, 1895. Lees and Chorlton, Phil. Mag., 1896. Oddone, Rend. R. Acc. d. Lincei, 1897. W. Voigt, Wied. Ann., 1898. Lees, Proc. Royal Society, 1898.

section; and, if this ratio be small enough, the temperature conditions to which the sides are subjected are of slight importance. For instance, the temperatures at points on the axis of a relatively thin disk, one face of which is kept at 0° C. and the other at 100° C., are not measurably different, whether the curved surface is kept at 0° C. or 100° C., from the temperatures at corresponding points on the axis of an infinite disk of the same thickness, the faces of which are kept at 0° C. and 100° C. respectively.

On the other hand, if the temperature gradient on the side faces could be made to follow the proper law, — or even if, for moderate values of $V_0 - V_l$, it could be kept constant, — the temperatures on the axis of the prism would be much the same, whether the prism were slender or stout.

In view of the extreme difficulty of controlling, or even of measuring with accuracy, the temperatures on the side faces of a prism, it seemed to us desirable to determine beforehand, as accurately as we could from theoretical considerations, under each of a number of different assumptions with respect to the side temperatures, how short a prism of given cross section must be in order that the temperatures on its axis, in the case mentioned above, might be sensibly the same as if its cross section were infinite in area.

We shall find it convenient to write down at the beginning of our discussion some of the common equations* of the theory of heat conduction in the forms which we shall need to use later on. If θ represents the temperature at the time t at any point, P, in an isotropic solid, the rate of flow of heat at this time, at P, in any direction, is usually assumed to be the product of a scalar point function, κ', and the negative of the space derivative, taken at P in the given direction, of a certain function of the temperature, $f(\theta)$. If, therefore, u, v, and w are the components, parallel to three mutually perpendicular co-ordinate axes, of the vector, q, which represents the flow within the solid,

$$u = -\kappa' \cdot \frac{\partial f(\theta)}{\partial x} = -\kappa' \cdot f'(\theta) \cdot \frac{\partial \theta}{\partial x},$$

$$v = -\kappa' \cdot f'(\theta) \cdot \frac{\partial \theta}{\partial y}, \qquad w = -\kappa' \cdot f'(\theta) \cdot \frac{\partial \theta}{\partial z}. \tag{1}$$

* Fourier, Théorie Analytique de la Chaleur. Poisson, Théorie Mathématique de la Chaleur. Lamé, Leçons sur la Théorie Analytique de la Chaleur. Kelvin, Article "Heat" in the Encyclopædia Britannica. Kelland, Brit. Assoc. Rep., 1841. Preston, Theory of Heat. Riemann, Partielle Differentialgleichungen.

If ξ, η, ζ are analytic point functions which define a system of orthogonal curvilinear co-ordinates, and h_ξ, h_η, h_ζ are the gradients of these functions, and if q_ξ, q_η, q_ζ are the components of the heat flux taken at every point normal to the surfaces of constant ξ, η, ζ which pass through that point,

$$q_\xi = -\kappa' . h_\xi . \frac{\partial f(\theta)}{\partial \xi}, \quad q_\eta = -\kappa' . h_\eta . \frac{\partial f(\theta)}{\partial \eta}, \quad q_\zeta = -\kappa' . h_\zeta . \frac{\partial f(\theta)}{\partial \zeta}. \quad (2)$$

For a given material which would be homogeneous if it were at the same temperature throughout, under given pressure conditions, κ' is assumed to be constant, so that $\kappa' f'(\theta)$ is a function of the temperature only. This product is called the specific conductivity of the substance under the given circumstances, and is denoted by $F'(\theta)$ or by κ. We may write, therefore,

$$u = -\kappa . \frac{\partial \theta}{\partial x} = -\frac{\partial F(\theta)}{\partial x}, \quad v = -\frac{\partial F(\theta)}{\partial y}, \quad w = -\frac{\partial F(\theta)}{\partial z}. \quad (3)$$

$$q_\xi = -h_\xi . \frac{\partial F(\theta)}{\partial \xi}, \quad q_\eta = -h_\eta . \frac{\partial F(\theta)}{\partial \eta}, \quad q_\zeta = -h_\zeta . \frac{\partial F(\theta)}{\partial \zeta}. \quad (4)$$

If a closed analytic surface, S, be drawn within the solid and if (ξ, n), (η, n), (ζ, n) represent the angles between the exterior normal to S at any point on it and the directions at that point in which ξ, η, and ζ increase most rapidly, the flux of heat across S from within outward may be written

$$\int \{ q_\xi \cdot \cos(\xi, n) + q_\eta \cdot \cos(\eta, n) + q_\zeta \cdot \cos(\zeta, n) \} \, dS. \quad (5)$$

The surface integral, taken over S, of $U \cos(\xi, n)$, where U is any function which, with its space derivatives of the first order, is continuous within and upon S, is equal to the volume integral, extended through the space enclosed by S, of $h_\xi . h_\eta . h_\zeta . \dfrac{\partial \left(\dfrac{U}{h_\eta h_\zeta} \right)}{\partial \xi}$, so that the flux across S may be expressed by the integral

$$\iiint h_\xi . h_\eta . h_\zeta \left\{ \frac{\partial \left(\dfrac{q_\xi}{h_\eta h_\zeta} \right)}{\partial \xi} + \frac{\partial \left(\dfrac{q_\eta}{h_\zeta h_\xi} \right)}{\partial \eta} + \frac{\partial \left(\dfrac{q_\zeta}{h_\xi h_\eta} \right)}{\partial \zeta} \right\} d\tau. \quad (6)$$

If $\psi(\theta)$ is the specific heat per unit volume of the body under the given pressure conditions, we may equate the expression just obtained to

$\iiint \psi(\theta) \cdot \frac{\partial \theta}{\partial t} \cdot d\tau$, and, since this result is independent of the form of S and of the volume of the space enclosed by it, at every point within the solid

$$\frac{\partial \theta}{\partial t} = -\frac{h_\xi \cdot h_\eta \cdot h_\zeta}{\psi(\theta)} \left\{ \frac{\partial \left(\frac{q_\xi}{h_\eta h_\zeta}\right)}{\partial \xi} + \frac{\partial \left(\frac{q_\eta}{h_\zeta h_\xi}\right)}{\partial \eta} + \frac{\partial \left(\frac{q_\zeta}{h_\xi h_\eta}\right)}{\partial \zeta} \right\}, \tag{7}$$

or
$$\frac{\partial \theta}{\partial t} = \frac{h_\xi \cdot h_\eta \cdot h_\zeta}{\psi(\theta)} \left\{ \frac{\partial}{\partial \xi}\left(\frac{\kappa' h_\xi}{h_\eta h_\zeta} \cdot \frac{\partial f(\theta)}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(\frac{\kappa' h_\eta}{h_\xi h_\zeta} \cdot \frac{\partial f(\theta)}{\partial \eta}\right) + \frac{\partial}{\partial \zeta}\left(\frac{\kappa' h_\zeta}{h_\xi h_\eta} \cdot \frac{\partial f(\theta)}{\partial \zeta}\right) \right\}, \tag{8}$$

or
$$\frac{\partial \theta}{\partial t} = \frac{h_\xi \cdot h_\eta \cdot h_\zeta}{\psi(\theta)} \left\{ \frac{\partial}{\partial \xi}\left(\frac{h_\xi}{h_\eta h_\zeta} \cdot \frac{\partial F(\theta)}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(\frac{h_\eta}{h_\xi h_\zeta} \cdot \frac{\partial F(\theta)}{\partial \eta}\right) + \frac{\partial}{\partial \zeta}\left(\frac{h_\zeta}{h_\xi h_\eta} \cdot \frac{\partial F(\theta)}{\partial \zeta}\right) \right\}, \tag{9}$$

three different forms of the equation of continuity.

In Cartesian co-ordinates, this equation becomes

$$\frac{\partial \theta}{\partial t} = \frac{1}{\psi(\theta)} \left\{ \frac{\partial}{\partial x}\left(\frac{\kappa' . \partial f(\theta)}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\kappa' . \partial f(\theta)}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\kappa' \, \partial f(\theta)}{\partial z}\right) \right\}$$
$$\equiv \frac{1}{\psi(\theta)} \cdot \nabla^2 F(\theta). \tag{10}$$

$$= \frac{1}{\psi(\theta)} \left\{ \frac{\partial}{\partial x}\left(F'(\theta) \cdot \frac{\partial \theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(F'(\theta) \cdot \frac{\partial \theta}{\partial y}\right) + \frac{\partial}{\partial z}\left(F'(\theta) \cdot \frac{\partial \theta}{\partial z}\right) \right\}. \tag{11}$$

If the flow of heat within a solid is steady, $\frac{\partial \theta}{\partial t}$ vanishes at every point, q is a solenoidal vector, and the equation of continuity in terms of Cartesian co-ordinates becomes

$$\frac{\partial}{\partial x}\left(\frac{\kappa' . \partial f(\theta)}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\kappa' . \partial f(\theta)}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\kappa' . \partial f(\theta)}{\partial z}\right) = 0. \tag{12}$$

Or

$$\frac{\partial}{\partial x}\left(F'(\theta) \cdot \frac{\partial \theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(F'(\theta) \cdot \frac{\partial \theta}{\partial y}\right) + \frac{\partial}{\partial z}\left(F'(\theta) \cdot \frac{\partial \theta}{\partial z}\right)$$
$$\equiv \nabla^2 F(\theta) = 0. \tag{13}$$

It is usually assumed that θ is continuous at the surface of separation of two isotropic solids of different conductivities. If n_1 and n_2 are normals at a point of such a surface drawn into the first and second conductors respectively, and if the flow of heat is steady,

$$\frac{\partial F_1(\theta)}{\partial n_1} + \frac{\partial F_2(\theta)}{\partial n_2} = 0, \quad \text{or} \quad \kappa'_1 \frac{\partial f_1(\theta)}{\partial n_1} + \kappa'_2 \frac{\partial f_2(\theta)}{\partial n_2} = 0,$$

$$\text{or} \quad \kappa_1 \frac{\partial \theta}{\partial n_1} + \kappa_2 \frac{\partial \theta}{\partial n_2} = 0. \tag{14}$$

If the temperature differences within a body are comparatively slight, we may often use Fourier's assumption and represent $f(\theta)$ approximately by θ itself. As we shall need to compare the solutions of certain simple problems in the steady flow of heat obtained on this hypothesis with the corresponding solutions obtained on the assumption that $f(\theta)$ and θ are not identical, we may note certain facts in passing. It is easy to prove by an elementary application of Green's Theorem that a function, V, which is harmonic within a given closed surface S, and which upon two given portions, S_1 and S_2, of S has the constant values C_1 and C_2 respectively, while at every other part of S its normal derivative is zero, is determined by these conditions. If this function has been found, it is easy to write down the unique function

$$V' \equiv \frac{C'_1 - C'_2}{C_1 - C_2} V + \frac{C'_2 C_1 - C_2 C'_1}{C_1 - C_2}, \tag{15}$$

which is harmonic within S, has the constant value C'_1 on S_1 and the constant value C'_2 on S_2, and the normal derivative of which vanishes at all points of S which do not belong to S_1 or S_2. The families of surfaces defined by the equations, $V =$ constant, $V' =$ constant, are identical. If, therefore, two given portions of the surface of a solid isotropic conductor in which there is a steady flow of heat be kept at constant temperatures (C_1 and C_2) while there is no flow across the rest of its surface, the function V, which on Fourier's hypothesis gives the temperatures at all points within the solid, is connected with the function V', which gives $f(\theta)$ on the assumption that this is not identical with θ itself, by means of the equation

$$V' \equiv \frac{f(C_1) - f(C_2)}{C_1 - C_2} V + \frac{C_1 \cdot f(C_2) - C_2 \cdot f(C_1)}{C_1 - C_2}, \tag{16}$$

and the forms of the isothermal surfaces are independent of the form of the function f.

Two harmonic functions can only have the same level surfaces when one is a linear function of the other. If upon n given portions, S_1, S_2, S_3, ... S_n, of a given closed surface, S, V has the constant values C_1, C_1, C_3, ... C_n, respectively, and V' the values, $F(C_1)$, $F(C_2)$, $F(C_3)$, ... $F(C_n)$, while upon the remainder of S, if there is any, the normal derivatives of V and V' are zero, and if V and V' are harmonic within S, V' cannot in general be expressed as a linear function of V, and, if n is greater than 2, their level surfaces will not usually coincide. If n is 3, the condition of coincidence is evidently

$$\begin{vmatrix} C_1 & F(C_1) & 1 \\ C_2 & F(C_2) & 1 \\ C_3 & F(C_3) & 1 \end{vmatrix} = 0. \tag{17}$$

If U has the constant values C_1, C_2, C_3; V the constant values K_1, K_2, K_3; and W the constant values L_1, L_2, L_3 on S_1, S_2, S_3, respectively, if the normal derivatives of these functions are equal to zero at every point of S not included in S_1, S_2, or S_3, and if all these functions are harmonic within S, W can always be expressed uniquely in the form $AU + BV + D$, unless

$$\begin{vmatrix} C_1 & K_1 & 1 \\ C_2 & K_2 & 1 \\ C_3 & K_3 & 1 \end{vmatrix} = 0. \tag{18}$$

Before we were able to decide upon the forms and dimensions of our apparatus and upon the manner in which it should be used, we found it desirable to make some rather elaborate computations based on the mathematical solutions of certain problems in heat conduction. In describing this work it will be convenient to state, first, some analytical results to which we shall afterwards give various physical interpretations. We have purposely put these preliminary statements in purely mathematical language lest they should seem to be narrower in their applications than they really are.

(1) The square bases of a rectangular parallelopiped of height l are $2a$ long and $2a$ broad. A function, V, harmonic within this parallelopiped, has the constant value V_0 at the lower base and the constant value V_l at the upper base. At every point of the other faces of the prism V satisfies the equation

$$\kappa \frac{\partial V}{\partial n} + h(V - \overline{V}) = 0, \tag{19}$$

where $\overline{V}$ is a constant, and $\dfrac{\partial V}{\partial n}$ represents the derivative of V taken in the direction of the exterior normal. If the origin of rectangular co-ordinates be taken at the centre of the lower base while the axes of x and y are parallel to the sides of this base, V is given by the equation

$$V \equiv \overline{V} + \sum_{p=1}^{p=\infty} c_p \cdot \cos(n_p y) \sum_{k=1}^{k=\infty} c_k \cdot \cos(n_k x)\ \Omega, \tag{20}$$

where Ω represents the quantity

$$\left[\frac{[(V_l-\overline{V})-(V_0-\overline{V})e^{-l\lambda_{p,k}}]e^{z\lambda_{p,k}}+[(V_0-\overline{V})e^{l\lambda_{p,k}}-(V_l-\overline{V})]\epsilon^{-z\lambda_{p,k}}}{\epsilon^{l\lambda_{p,k}}-\epsilon^{-l\lambda_{p,k}}}\right].$$

Here n_1, n_2, n_3, etc. are the successive roots of the equation

$$\kappa n \,.\, \tan(n a) = h,$$

and $\lambda_{p,k}$ stands for the radical $\sqrt{n_p^2 + n_k^2}$, while c_1, c_2, c_3, etc. are the coefficients of the successive terms in the development,

$$1 = c_1 \cos(n_1 \theta) + c_2 \cos(n_2 \theta) + c_3 \cos(n_3 \theta) + \ldots\ldots$$

so that
$$c_k \equiv 4 \sin(n_k a) \div (2 n_k a + \sin(2 n_k a)).$$

It is to be noticed that equation (20) would give, on Fourier's assumptions, the final temperatures within a homogeneous parallelopiped of specific internal conductivity κ, and of external conductivity h, if the lower base were kept at the constant temperature V_0 and the upper base at the constant temperature V_l, while the sides were exposed to the atmosphere at the temperature $\overline{V}$. In this result the absolute dimensions of the parallelopiped are inextricably involved with the value of h / κ.

(2) The square bases of a rectangular parallelopiped of height l are $2a$ long and $2a$ broad. A function, V, harmonic within this parallelopiped, has the constant value V_0 at the lower square base, the constant value V_l at the upper base, and the constant value $\overline{V}$ on the other faces of the parallelopiped. If, then, the centre of the lower base be used as origin of co-ordinates, with axes of x and y parallel to sides of the base, V is given by the equation

$$V \equiv \overline{V} + \sum_{p=1}^{p=\infty} \sum_{q=1}^{q=\infty} (-1)^{\frac{p+q-2}{2}} \cdot \frac{4^2}{p q \pi^2} \cdot \cos\left(\frac{p \pi x}{2a}\right) \cdot \cos\left(\frac{q \pi y}{2a}\right) . \Phi, \tag{21}$$

where Φ represents the quantity

$$\left\{\frac{(V_l - \overline{V})\sinh\left(\frac{\pi z}{2a}\sqrt{p^2+q^2}\right) - (V_0 - \overline{V})\sinh\left(\frac{\pi(z-l)\sqrt{p^2+q^2}}{2a}\right)}{\sinh\left(\frac{l\pi}{2a}\sqrt{p^2+q^2}\right)}\right\},$$

and where p and q are integers.

V is evidently the temperature on Fourier's hypothesis within the parallelopiped, if its bases and sides are kept at the temperatures V_0, V_l, and $\overline{V}$ respectively, when the flow is steady. In this case the specific conductivity of the material of which the homogeneous parallelopiped is made does not affect the temperatures within the solid, and the relative, not the absolute, dimensions of the parallelopiped are of importance. The interpretation of the equation (21) when $f(\theta)$ and θ are assumed to be different is obvious.

(3) A function V, which involves the time and the distance from the co-ordinate plane $z = 0$, is continuous, as are $\frac{\partial V}{\partial t}$, $\frac{\partial V}{\partial z}$, $\frac{\partial^2 V}{\partial z^2}$, in the region R, bounded by the planes $z = 0$, $z = l$. Within R, V satisfies the equation $\frac{\partial V}{\partial t} = a^2 \frac{\partial^2 V}{\partial z^2}$. V vanishes when $z = l$, and has the constant value V_0 when $z = 0$, whatever t is. If, when $t = 0$, $V = V_0 \phi(z)$ for all points within R,

$$V = V_0\left[1 - \frac{z}{l} + \frac{2}{l}\sum_{m=0}^{m=\infty} e^{-\frac{m^2 a^2 \pi^2 t}{l^2}} \sin\left(\frac{m\pi z}{l}\right) \cdot \int_0^l [\psi(\lambda) + \frac{\lambda}{l} - 1] \sin\frac{m\pi\lambda}{l}\, d\lambda\right]. \tag{22}$$

If $\phi(z)$ has the constant value c,

$$V = V_0\left[1 - \frac{z}{l} + \frac{2}{\pi}\left\{(2c-1)\,[e^{-\frac{t}{T}}\sin\frac{\pi z}{l} + \tfrac{1}{3}e^{-\frac{9t}{T}}\sin\frac{3\pi z}{l} + \tfrac{1}{5}e^{-\frac{25t}{T}}\sin\frac{5\pi z}{l} + \ldots] - [\tfrac{1}{2}e^{-\frac{4t}{T}}\sin\frac{2\pi z}{l} + \tfrac{1}{4}e^{-\frac{16t}{T}}\sin\frac{4\pi z}{l} + \ldots]\right\}\right], \tag{23}$$

where $T = l^2 / a^2\pi^2$.

Equation (23) would give, on Fourier's assumptions, the temperatures at any time within a homogeneous infinite plane lamina of thickness l initially at the uniform temperature $c V_0$, if, from the time $t = 0$, one face were kept at the constant temperature V_0 and the other at the constant temperature zero.

(4) The radius of the base of a right cylinder of revolution of length l is a. A function, V, harmonic within this cylinder, has the constant value V_0 on one (the lower) base, the constant value V_l on the upper base, and the constant value $\overline{V}$ on the convex surface. If, then, the axis of the cylinder be used as axis of z with origin at the centre of the lower base, V is given by the equation

$$V = V + 2 \sum_{p=1}^{p=\infty} \frac{J_0\left(\frac{x_p r}{a}\right)\left\{(V_0 - \bar{V}) \sinh\left(\frac{x_p(l-z)}{a}\right) + (V_l - V) \sinh\left(\frac{x_p z}{a}\right)\right\}}{x_p \,.\, J_1(x_p) \,.\, \sinh\left(\frac{x_p \,.\, l}{a}\right)}, \tag{24}$$

where J_0 and J_1 represent Bessel's Function of the zeroth and first order, respectively, and x_p is the pth root in order of magnitude of the equation $J_0(x) = 0$. The first ten values of x for which the Bessel's Function of the zeroth order vanishes have been given by Meissel.* We have computed the next thirty values of the x_p's by the aid of Stokes's Formula,† and the values of the Bessel's Function of the first order corresponding to these forty x_p's either from the series which usually defines $J_1(x)$ or from the semi-convergent series. This computation was done by means of Vega's ten place table of logarithms,‡ except in the few cases where a greater number of places was necessary, and for these we had recourse to Thoman's tables.§ All the values have been checked by duplicate computation, and the first four values of $J_1(x)$ by comparison with Meissel's tables. The results of this work appear in Table I. Table II. gives to seven places of decimals the values of the x_p's from $p = 41$ to $p = 65$. The values of V on the axis of the cylinder depend upon the corresponding values of the function

$$S \equiv \sum_{p=1}^{p=\infty} \left\{ \frac{\sinh\left(\frac{x_p z}{a}\right)}{x_p \,.\, J(x_p) \sinh\left(\frac{x_p l}{a}\right)} \right\},$$

* Meissel, Math. Abhandlungen der k. Akad. der Wissenschaften zu Berlin, 1888.

† Stokes, Camb. Phil. Trans., IX. Lommel, Studien über die Bessel'schen Functionen, Leipzig, 1868. Rayleigh, The Theory of Sound, London, 1878. Byerly, Treatise on Fourier's Series, etc., Boston, 1893. Gray and Mathews, Bessel Functions and their Applications to Physics.

‡ Vega, Thesaurus Logarithmorum Completus, Lipsiæ, 1794.

§ Thoman, Tables de Logarithmes à 27 Décimales pour les Calculs de Précision, Paris, 1867.

TABLE I.

The pth *Root in Order of Magnitude of the Equation* $J_0(x) = 0$ *is denoted by* x_p.

p	x_p	Log x_p	$J_1(x_p)$	Log.$(\pm J_1(x_p))$
1	2.4048255577	0.3810835788	+0.51914750	9.7152908
2	5.5200781103	0.7419452231	−0.34026481	9.5318170
3	8.6537279129	0.9372032361	+0.27145230	9.4336935
4	11.7915344391	1.0715703238	−0.23245983	9.3663479
5	14.9309177086	1.1740865018	+0.20654642	9.3150177
6	18.0710639679	1.2569837232	−0.18772880	9.2735309
7	21.2116366299	1.3265741787	+0.17326589	9.2387131
8	24.3524715308	1.3865430443	−0.16170155	9.2087142
9	27.4934791320	1.4392297006	+0.15218121	9.1823610
10	30.6346064684	1.4862123057	−0.14416598	9.1588628
11	33.7758202136	1.5286059043	+0.13729694	9.1376609
12	36.9170983537	1.5672275586	−0.13132463	9.1183462
13	40.0584257646	1.6026938781	+0.12606950	9.1006100
14	43.1997917132	1.6354816528	−0.12139863	9.0842138
15	46.3411883717	1.6659671666	+0.11721120	9.0689691
16	49.4826098974	1.6944525978	−0.11342918	9.0547248
17	52.6240518411	1.7211842839	+0.10999114$_5$	9.0413577
18	55.7655107550	1.7463656842	−0.10684789	9.0287659
19	58.9069839261	1.7701667872	+0.10395957	9.0168645
20	62.0484691902	1.7927310714	−0.10129350	9.0055816

TABLE I. — *Continued.*

The p*th Root in Order of Magnitude of the Equation* $J_0(x) = 0$ *is denoted by* x_p.

p	x_p	Log x_p	$J_1(x_p)$	Log $(\pm J_1(x_p))$
21	65.1899648002	1.8141807465	+0.09882255	8.9948561
22	68.3314693299	1.8346207594	−0.09652404	8.9846355
23	71.4729816036	1.8541418997	+0.09437879	8.9748744
24	74.6145006437	1.8728232368	−0.09237051	8.9655333
25	77.7560256304	1.8907340543	+0.09048519	8.9565775
26	80.8975558711	1.9079354006	−0.08871080	8.9479765
27	84.0390907769	1.9244813451	+0.08703686	8.9397032
28	87.1806298436	1.9404200023	−0.08545424	8.9317336
29	90.3221726372	1.9557943757	+0.08395493	8.9240462
30	93.4637187819	1.9706430570	−0.08253186	8.9166216
31	96.6052679510	1.9850008094	+0.08117879	8.9094426
32	99.7468198587	1.9988990584	−0.07989015	8.9024933
33	102.8883742542	2.0123663047	+0.07866100	8.8957595
34	106.0299309165	2.0254284784	−0.07748689	8.8892282
35	109.1714896498	2.0381625681	+0.07635913	8.8828610
36	112.3130502805	2.0504302219	−0.07528823	8.8767271
37	115.4546126537	2.0624112882	+0.07425684	8.8707365
38	118.5961766309	2.0740706879	−0.07326670	8.8649067
39	121.7377420880	2.0854252422	+0.07231515	8.8592293
40	124.8793089132	2.0964904866	−0.07139973	8.8536966

TABLE II.

The p*th Root in Order of Magnitude of the Equation* $J_0(x) = 0$ *is denoted by* x_p.

p	x_p	Log x_p	Log $\sqrt{\frac{2}{\pi x_p}}$
41	128.02087701	2.10728080	8.8482997
42	131.16244628	2.11780951	8.8430353
43	134.30401664	2.12808900	8.8378956
44	137.44558802	2.13823080	8.8328247
45	140.58716035	2.14794566	8.8279672
46	143.72873357	2.15754360	8.8231683
47	146.87030763	2.16693400	8.8184731
48	150.01188246	2.17617471	8.8138527
49	153.15345802	2.18512681	8.8093767
50	156.29503427	2.19394518	8.8049675
51	159.43601116	2.20258642	8.8006469
52	162.57818867	2.21106228	8.7964089
53	165.71976675	2.21937431	8.7922529
54	168.86134537	2.22753025	8.7881749
55	172.00292450	2.23553583	8.7841721
56	175.14450412	2.24339651	8.7802418
57	178.28608520	2.25111745	8.7763813
58	181.42766471	2.25870351	8.7725883
59	184.56924564	2.26615934	8.7688604
60	187.71082696	2.27348932	8.7651954
61	190.85240865	2.28069765	8.7615912
62	193.99399070	2.28778828	8.7580459
63	197.13557308	2.29476500	8.7545576
64	200.27715580	2.30163142	8.7511244
65	203.41873881	2.30838096	8.7477496

and these latter we have computed for certain values of z / l and a / l by the help of Gudermann's tables.* The results appear in Table III. To avoid possible errors arising from combining so many quantities, we generally used seven places, although the time required for the computation, which was done in duplicate, was thereby increased by some weeks.

* Gudermann, Theorie der Potenzial oder Cyklisch-hyperbolischen Functionen, Berlin, 1833. Willson and Peirce, Bulletin of the American Mathematical Society, 1897.

TABLE III.

$$S \equiv \sum_{0}^{\infty} \left\{ \frac{\sinh\left(\frac{x_p z}{a}\right)}{x_p J_1(x_p) \sinh\left(\frac{x_p l}{a}\right)} \right\}.$$

	$z = 0$	$z = \frac{1}{4} l$	$z = \frac{1}{2} l$	$z = \frac{3}{4} l$	$z = l$
$a = \frac{1}{4} l$	0	0.0006	0.0065	0.0703	0.5
$a = \frac{1}{2} l$	0	0.0196	0.0697	0.2116	0.5
$a = \frac{3}{4} l$	0	0.0558	0.1427	0.2908	0.5
$a = l$	0	0.0857	0.1920	0.3320	0.5
$a = \frac{3}{2} l$	0	0.1144	0.2349	0.3642	0.5
$a = 2\,l$	0	0.1224	0.2464	0.3724	0.5
$a = 3\,l$	0	0.1249	0.2498	0.3748	0.5
$a = 5\,l$	0	0.1250	0.2500	0.3750	0.5

We shall wish to base an argument upon the values of S given in the last line of Table III., and upon certain corresponding values of the quantity

$$T \equiv \sum_{0}^{\infty} \frac{J_0\left(\frac{x_p r}{a}\right) \cdot \sinh\left(\frac{x_p z}{a}\right)}{x_p \cdot J_1(x_p) \cdot \sinh\left(\frac{x_p l}{a}\right)}. \tag{25}$$

We print, therefore, in Tables V. and VI., the numerical values of the terms of the series which define these functions in the cases in question.

It is evident that the three values of S are in reality less than 0.125, 0.250, 0.375, respectively, though by quantities far too small to appear in our results. Unavoidable errors introduced by adding together, in some instances, hundreds of numbers determined by logarithms, make the last figures given doubtful. Although our computations were made throughout with the aid of seven place and ten place tables, we have contented ourselves with four places in tabulating the values of T. It is interesting

to notice the seemingly anomalous sequence of values in the terms of the series for T. In fact, the relations between the successive terms is, for some cases that we have studied, so complicated that the detection of accidental errors of computation becomes extremely difficult. $T = 0$ when $r = a_1$ whatever z is, and equation (24) can be written in the form

$$V = \bar{V}(1 - 2\,T_z - 2\,T_{l-z}) + 2\,V_l\,T_z + 2\,V_0\,T_{l-z}.$$

TABLE IV.

a/l	z/l	$2\,S_z$	$1 - 2\,S_{l-z}$	$\frac{1}{2} + S_z - S_{l-z}$	$\frac{1}{2} - S_z - S_{l-z}$
$\frac{1}{4}$	$\frac{1}{4}$	.0012	.8595	.4303	.4291
$\frac{1}{4}$	$\frac{1}{2}$	.0130	.9870	.5000	.4870
$\frac{1}{4}$	$\frac{3}{4}$	.1405	.9988	.5695	.4291
$\frac{1}{2}$	$\frac{1}{4}$	.0395	.5768	.3080	.2688
$\frac{1}{2}$	$\frac{1}{2}$	.1393	.8607	.5000	.3606
$\frac{1}{2}$	$\frac{3}{4}$	.4232	.9607	.6920	.2688
$\frac{3}{4}$	$\frac{1}{4}$	.1117	.4185	.2651	.1534
$\frac{3}{4}$	$\frac{1}{2}$	.2854	.7146	.5000	.2146
$\frac{3}{4}$	$\frac{3}{4}$	.5815	.8883	.7349	.1534
1	$\frac{1}{4}$	.1714	.3359	.2536	.0823
1	$\frac{1}{2}$	.3839	.6161	.5000	.1160
1	$\frac{3}{4}$	.6641	.8286	.7463	.0823
$\frac{3}{2}$	$\frac{1}{4}$	.2288	.2716	.2502	.0214
$\frac{3}{2}$	$\frac{1}{2}$	.4698	.5302	.5000	.0302
$\frac{3}{2}$	$\frac{3}{4}$	.7284	.7712	.7498	.0214
2	$\frac{1}{4}$	.2449	.2552	.2501	.0052
2	$\frac{1}{2}$	.4927	.5073	.5000	.0062
2	$\frac{3}{4}$	.7448	.7551	.7499	.0052
3	$\frac{1}{4}$	.2497	.2503	.2500	.0003
3	$\frac{1}{2}$	.4996	.5004	.5000	.0004
3	$\frac{3}{4}$	.7497	.7503	.7500	.0003
5	$\frac{1}{4}$	.2500	.2500	.2500	.0000
5	$\frac{1}{2}$	.5000	.5000	.5000	.0000
5	$\frac{3}{4}$	.7500	.7500	.7500	.0000

TABLE V.

$$S \equiv \sum_{0}^{\infty} \left\{ \frac{\sinh\left(\frac{x_p z}{5l}\right)}{x_p \, . \, J_1(x_p) \sinh\left(\frac{x_p}{5}\right)} \right\}.$$

p	$z = \frac{1}{4} l$	$z = \frac{1}{2} l$	$z = \frac{3}{4} l$
1	+0.1931944	+0.389186	+0.590810
2	—0.1108619	—0.230224	—0.367236
3	+0.0694976	+0.152211	+0.263868
4	—0.0434740	—0.102502	—0.198205
5	+0.0268426	+0.069353	+0.152345
6	—0.0163951	—0.047111	—0.118978
7	+0.0099432	+0.032159	+0.094069
8	—0.0060054	—0.022070	—0.075105
9	+0.0036196	+0.015227	+0.060435
10	—0.0021801	—0.010557	—0.048940
11	+0.0013132	+0.007351	+0.039837
12	—0.0007914	—0.005139	—0.032567
13	+0.0004777	+0.003604	+0.026720
14	—0.0002886	—0.002536	—0.021990
15	+0.0001746	+0.001789	+0.018143
16	—0.0001057	—0.001264	—0.015007
17	+0.0000641	+0.000896	+0.012439
18	—0.0000389	—0.000635	—0.010325
19	+0.0000237	+0.000452	+0.008588
20	—0.0000144	—0.000321	—0.007150
21	+0.0000088	+0.000229	+0.005962
22	—0.0000053	—0.000163	—0.004975
23	+0.0000033	+0.000117	+0.004159
24	—0.0000020	—0.000083	—0.003479
25	+0.0000012	+0.000060	+0.002912
26	—0.0000007	—0.000043	—0.002441
27	+0.0000005	+0.000031	+0.002046
28	—0.0000002	—0.000022	—0.001717
29	+0.0000001	+0.000015	+0.001442
30	—0.0000001	—0.000011	—0.001211
31	. . .	+0.000008	+0.001018
32	. . .	—0.000006	—0.000856
33	. . .	+0.000004	+0.000721
34	. . .	—0.000003	—0.000607
35	. . .	+0.000002	+0.000511
36	. . .	—0.000002	—0.000430

TABLE V. — *Continued.*

p	$z = \frac{1}{4} l$	$z = \frac{1}{2} l$	$z = \frac{3}{4} l$
37	. . .	+0.000001	+0.000363
38	. . .	—0.000001	—0.000306
39	. . .	. . .	+0.000258
40	. . .	. . .	—0.000218
41	. . .	. . .	+0.000184
42	. . .	. . .	—0.000155
43	. . .	. . .	+0.000130
44	. . .	. . .	—0.000110
45	. . .	. . .	+0.000094
46	. . .	. . .	—0.000079
47	. . .	. . .	+0.000067
48	. . .	. . .	—0.000057
49	. . .	. . .	+0.000048
50	. . .	. . .	—0.000040
51	. . .	. . .	+0.000034
52	. . .	. . .	—0.000029
53	. . .	. . .	+0.000025
54	. . .	. . .	—0.000021
55	. . .	. . .	+0.000018
56	. . .	. . .	—0.000015
57	. . .	. . .	+0.000013
58	. . .	. . .	—0.000011
59	. . .	. . .	+0.000009
60	. . .	. . .	—0.000008
61	. . .	. . .	+0.000007
62	. . .	. . .	—0.000006
63	. . .	. . .	+0.000005
64	. . .	. . .	—0.000004
65	. . .	. . .	+0.000003
66	. . .	. . .	—0.000002
67	. . .	. . .	+0.000001
	0.1250000	0.250002	0.375004

TABLE VI.

$$T \equiv \sum_{0}^{\infty} \frac{J_0\left(\frac{x_p}{5}\right) \sinh\left(\frac{x_p z}{5\,l}\right)}{x_p \,.\, J_1(x_p) \sinh\left(\frac{x_p}{5}\right)}.$$

p	$z = \frac{1}{4} l$	$z = \frac{1}{2} l$	$z = \frac{3}{4} l$
1	+0.182182	+0.367002	+0.557133
2	–0.079568	–0.165236	–0.263573
3	+0.026424	+0.057870	+0.100321
4	–0.001060	–0.002499	–0.004832
5	–0.006854	–0.017708	–0.038898
6	+0.006445	+0.018519	+0.046768
7	–0.003686	–0.011920	–0.034875
8	+0.001315	+0.004833	+0.016446
9	–0.000029	–0.000120	–0.000477
10	–0.000401	–0.001943	–0.009010
11	+0.000381	+0.002131	+0.011547
12	–0.000222	–0.001441	–0.009131
13	+0.000080	+0.000609	+0.004513
14	–0.000001	–0.000009	–0.000082
15	–0.000026	–0.000270	–0.002743
16	+0.000025	+0.000304	+0.003602
17	–0.000015	–0.000210	–0.002918
18	+0.000006	+0.000090	+0.001471
19	–0.000000	–0.000001	–0.000020
20	–0.000002	–0.000042	–0.000939
21	+0.000002	+0.000048	+0.001249
22	–0.000001	–0.000034	–0.001024
23	+0.000000	+0.000012	+0.000522
24	. . .	–0.000000	–0.000006
25	. . .	–0.000007	–0.000342
26	. . .	+0.000008	+0.000456
27	. . .	–0.000006	–0.000382
28	. . .	+0.000003	+0.000194
29	. . .	–0.000000	–0.000001
30	. . .	–0.000001	–0.000133
31	. . .	+0.000001	+0.000176
32	. . .	–0.000001	–0.000146
33	. . .	+0.000000	+0.000075
34	. . .	–0.000000	–0.000001
35	. . .	. . .	–0.000051
36	. . .	. . .	+0.000069

TABLE VI. — *Continued.*

p	$z = \frac{1}{4} l$	$z = \frac{1}{2} l$	$z = \frac{3}{4} l$
37	. . .	. . .	—0.000057
38	. . .	. . .	+0.000030
39	. . .	. . .	—0.000000
40	. . .	. . .	—0.000020
41	. . .	. . .	+0.000028
42	. . .	. . .	—0.000023
43	. . .	. . .	+0.000012
44	. . .	. . .	—0.000000
45	. . .	. . .	—0.000008
46	. . .	. . .	+0.000011
47	. . .	. . .	—0.000009
48	. . .	. . .	+0.000005
49	. . .	. . .	—0.000000
50	. . .	. . .	—0.000003
51	. . .	. . .	+0.000005
52	. . .	. . .	—0.000004
53	. . .	. . .	+0.000002
54	. . .	. . .	—0.000000
55	. . .	. . .	—0.000001
56	. . .	. . .	+0.000002
57	. . .	. . .	—0.000002
58	. . .	. . .	+0.000001
59	. . .	. . .	—0.000000
60	. . .	. . .	—0.000000
	+0.1250—	+0.2500—	+0.3749+

(5) The radius of the base of a right cylinder of revolution of height l is a. The centre of the lower base is used as the origin of a system of columnar co-ordinates (r, θ, z), the axis of the cylinder being the axis of z. A function V, which is continuous everywhere within the cylinder, has the value zero on the curved surface and on the lower base, and the constant value V_l on the upper base. The planes $z = l'$, $z = l''$, divide the cylinder into three portions (1), (2), and (3), in which V is represented analytically by three functions, V_1, V_2, V_3, respectively. If, when $z = l'$, $k_1 \dfrac{\partial V_1}{\partial z} = k_2 \dfrac{\partial V_2}{\partial z}$, and when $z = l''$, $k_2 \dfrac{\partial V_2}{\partial z} = k_3 \dfrac{\partial V_3}{\partial z}$, where k_1, k_2, k_3 are given constants, V_1, V_2, V_3 are given by the equations

$$V_1 \equiv \sum_{p=0}^{p=\infty} A_1 \,.\, J_0\left(\frac{x_p\, r}{a}\right) . \sinh\left(\frac{x_p\, z}{a}\right), \tag{26}$$

$$V_2 \equiv \sum_{p=0}^{p=\infty} J_0\left(\frac{x_p\, r}{a}\right)\left[A_2 \sinh\left(\frac{x_p\, z}{a}\right) + B_2 \cosh\left(\frac{x_p\, z}{a}\right)\right], \tag{27}$$

$$V_3 \equiv \sum_{p=0}^{p=\infty} J_0\left(\frac{x_p\, r}{a}\right)\left[A_3 \sinh\left(\frac{x_p\, z}{a}\right) + B_3 \cosh\left(\frac{x_p\, z}{a}\right)\right], \tag{28}$$

where A_1, A_2, A_3, B_2, and B_3 are subject to the conditions

$$A_1 \sinh\left(\frac{x_p\, l'}{a}\right) = A_2 \sinh\left(\frac{x_p\, l'}{a}\right) + B_2 \cosh\left(\frac{x_p\, l'}{a}\right), \tag{29}$$

$$k_1\, A_1 \cosh\left(\frac{x_p\, l'}{a}\right) = k_2\left[A_2 \cosh\left(\frac{x_p\, l'}{a}\right) + B_2 \sinh\left(\frac{x_p\, l'}{a}\right)\right],$$

$$A_2 \sinh\left(\frac{x_p\, l''}{a}\right) + B_2 \cosh\left(\frac{x_p\, l''}{a}\right) = A_3 \sinh\left(\frac{x_p\, l''}{a}\right) + B_3 \cosh\left(\frac{x_p\, l''}{a}\right),$$

$$k_2\left[A_2 \cosh\left(\frac{x_p\, l''}{a}\right) + B_2 \sinh\left(\frac{x_p\, l''}{a}\right)\right] = k_3\left[A_3 \cosh\left(\frac{x_p\, l''}{a}\right) + B_3 \sinh\left(\frac{x_p\, l''}{a}\right)\right],$$

$$A_3 \sinh\left(\frac{x_p\, l}{a}\right) + B_3 \cosh\left(\frac{x_p\, l}{a}\right) = \frac{2\, V_l}{x_p\, J_1(x_p)},$$

and where x_p is the pth root in order of magnitude of the Bessel's Equation $J_0(x) = 0$.

If, for brevity, we denote the quantities

$$\sinh\left(\frac{x_p \,.\, l}{a}\right),\quad \cosh\left(\frac{x_p \,.\, l}{a}\right),\quad \sinh\left(\frac{x_p \,.\, l'}{a}\right),\quad \cosh\left(\frac{x_p \,.\, l'}{a}\right),$$

$$\sinh\left(\frac{x_p \,.\, l''}{a}\right),\quad \cosh\left(\frac{x_p \,.\, l''}{a}\right),\quad \frac{2\, V_l}{x_p \,.\, J_1(x_2)},$$

by s, c, s', c', s'', c'', and Ω, respectively, these equations of condition may be written

$$A_1 s' = A_2 s' + B_2 c', \qquad k_1 A_1 c' = k_2 (A_2 c' + B_2 s'),$$
$$A_2 s'' + B_2 c'' = A_3 s'' + B_3 c'', \quad k_2 A_2 c'' + k_2 B_2 s'' = k_3 A_3 c'' + k_3 B_3 s'',$$
$$A_3 s + B_3 c = \Omega .$$

The determinant of the coefficients of the s's and c's may be reduced to the form

$$\frac{1}{c}\begin{vmatrix} c' s' (k_1 - k_2) & 0 & k_1 c'^2 - k_2 s'^2 \\ c s'' & s c'' - c s'' & c c'' \\ k_2 c c'' & k_3 (s s'' - c c'') & k_2 c s'' \end{vmatrix} \tag{30}$$

and

$$A_1 = \frac{- k_2 k_3 c \Omega}{c's'(k_1 - k_2)\{k_2 c s''(sc'' - cs'') + k_3 cc''(cc'' ss'')\} + (k_1 c'^2 - k_2 s'^2)\{cs'' k_3(ss'' - cc'') + k_2 cc''(s''c - sc'')\}} \tag{31}$$

If in the special case where k_1 and k_3 are equal, we write $k_1 = \mu\, k_2 = k_3$, we get

$$A_1 = \frac{- \mu \Omega}{c's'(\mu - 1)\{s''(sc'' - cs'') + \mu c''(cc'' - ss'')\} + (\mu c'^2 - s'^2)\{\mu s''(ss'' - cc'') + c''(s''c - sc'')\}} \tag{32}$$

with corresponding values for the other coefficients.

We shall need at the outset only two or three applications of the foregoing theory. We may ask first what must be the relative dimensions of a homogeneous regular right prism, one end of which is kept at the uniform temperature θ_0 and the other end at the uniform temperature θ_l, while its other faces are kept at some uniform temperature $\bar{\theta}$, between θ_0 and θ_l, in order that the temperatures on the axis of the prism in the final state shall be sensibly the same whatever value $\bar{\theta}$ has. If, for instance, the difference between θ_0 and θ_l is 100° C., what must be the ratio of the radius a of the circumference inscribed in a right section of the prism to the height l of the prism, in order that the temperature of every point on the axis may be the same within less than 0°.01 C., whether $\bar{\theta}$ is equal to θ_0 or to θ_l? Since we need merely to find a lower limit for $a \div l$, we shall do well to substitute for the prism the inscribed right cylinder of revolution, and then apply the solution of Problem 4 given above. We are to find a function of r and z, harmonic for values of r between 0 and a and values of z between 0 and l, which (1) has the uniform value $F(\theta_0)$ when $z = 0$, whatever r is; (2) has the uniform value $F(\theta_l)$

when $z = l$, whatever r is; and (3) has the uniform value $F(\bar{\theta})$ when $r = a$, whatever z is. The value of this function $F(\theta)$ is evidently

$$F(\bar{\theta}) \cdot (1 - 2\,T_{l-z} - 2\,T_z) + 2\,F(\theta_0) \cdot T_{l-z} + 2\,F(\theta_l) \cdot T_z, \qquad (33)$$

or, for points on the axis,

$$F(\bar{\theta})\,\{1 - 2\,S_{l-z} - 2\,S_z\} + 2\,F(\theta_0) \cdot S_{l-z} + 2\,F(\theta_l) \cdot S_z; \qquad (34)$$

that is,

$$F(\theta) - F(\theta_0) = 2\,S_z[F(\theta_l) - F(\theta_0)] + [F(\bar{\theta}) - F(\theta_0)]\,(1 - 2\,S_{l-z} - 2\,S_z). \qquad (35)$$

In the case of an infinite lamina, where $\dfrac{z}{a} = 0$, $\dfrac{l}{a} = 0$,

$$F(\theta) = F(\theta_0) + \frac{z}{l}\,(F(\theta_l) - F(\theta_0)). \qquad (36)$$

The difference between the values, at any point, of $F(\theta)$ in the case of the infinite lamina and in the case $a = 5\,l$, is

$$[F(\theta_l) - F(\theta_0)]\left[2\,S_z - \frac{z}{l}\right] + [F(\bar{\theta}) - F(\theta_0)]\,[1 - 2\,S_{l-z} - 2\,S_z].$$

It is easy to prove that for given values of l and a, $1 - 2\,S_{l-z} - 2\,S_z$ has its greatest value when $z = \frac{1}{2}\,l$, and if $a \div l$ is as great as 5, it is clear from Table V. that neither $1 - 2\,S_{l-z} - 2\,S_z$ nor $\left(2\,S_z - \dfrac{z}{l}\right)$ can for any point of the axis be nearly so great as 0.00001, so that whatever $\bar{\theta}$ is, the value of $F(\theta)$ is surely equal, within less than one ten-thousandth part of the greater of the quantities $F(\theta_l) - F(\theta_0)$, $F(\bar{\theta}) - F(\theta_0)$, to the value which it would have at the same point on the axis if the disk were infinite. By exactly what amount the temperatures themselves would differ in the two cases cannot be stated unless we know something of the nature of the function F.

For certain substances, experiment seems to show that within wide limits $F(\theta)$ can be expressed as a linear function of θ, as Fourier assumed. In the case of any one of these substances we may say, for example, that the final temperature at a point on the axis of a disk the radius of which is at least five times its thickness, if one face is kept at 100° C. and the other at 0° C., cannot be changed by nearly so much as 0°.01 C. by altering the temperature of the edge of the disk from 0° C.

to 100° C. The effect of radiation or conduction from the edge is therefore of no consequence.

Most experimenters have been able to reproduce mathematically the results of their work on thermal conductivities by assuming that in every case the conductivity, κ, is a linear function of θ, say $\kappa'(1 + 2b\theta)$, where b is small (usually less than .003), so that $F(\theta) = C + \kappa'\theta(1 + b\theta)$. On this assumption the temperatures within an infinite disk would be given by the equation,

$$\kappa'\theta(1 + b\theta) = \frac{\kappa' z}{l}\{\theta_l(1 + b\theta_l) - \theta_0(1 + b\theta_0)\} + \kappa'\theta_0(1 + b\theta_0), \quad (37)$$

or $$b(\theta^2 - \theta_0^2) + (\theta - \theta_0) = \frac{z}{l}\{\theta_l - \theta_0 + b(\theta_l^2 - \theta_0^2)\}.$$

Except in instances where near certain temperatures some great chemical or physical changes take place in the materials concerned, experiment appears to show that κ always changes slowly with the temperature, and, whether or not we know the exact nature of the connection between the two, it is easy to get a superior limit for the effect on the final temperatures at points on the axis of such a disk as has just been described, of changes in the edge temperatures. Neither in our own experience nor in any published reports that have come to our notice have we found any substance in which the change of κ with θ is so rapid that in a disk, where $a \geqq 5\,l$, made of it, with its faces kept at 0° C. and 100° C. respectively, the final temperatures of points on the axis could be affected by nearly so much as 0°.01 C. by changing the edge temperature from 0° C. to 100° C. We are here concerned merely with the magnitude of a possible error, and in every case to which we need to apply our theory we shall be well within bounds if we assume that the error is not greater than twice the error which would be found if θ and $f(\theta)$ were identical, as Fourier assumed them to be. We have, therefore, tabulated for a numerical example the final temperatures computed on Fourier's hypothesis at several points on the axis of a disk of radius a and length l, when one face ($z = 0$) is kept at the uniform temperature 0° C. and the other face ($z = l$) at the uniform temperature 100° C. on two or three different assumptions with respect to the edge temperatures. If the face temperatures are θ_0 and θ_l, and if the temperature has the same value, $\bar{\theta}$, at all points of the edge, the final axial temperatures are given by the equation

$$\theta = \bar{\theta}(1 - 2S_z - 2S_{l-z}) + 2\theta_0 S_{l-z} + 2\theta_l S_z,$$

and from this expression, with the help of the numbers in the body of Table IV., many special problems can be solved with very little labor. The expression

$$A\,(1 - 2\,T_z - 2\,T_{l-z}) + 2\,B\,T_{l-z} + 2\,\theta_l\,.\,T_z + (\theta_0 - B)\left(1 - \frac{z}{l}\right)$$

gives the final temperatures in a homogeneous disk of radius a and height l, one face ($z = 0$) of which is kept at the uniform temperature θ_0, the other face ($z = l$) at the uniform temperature θ_l, and the rim at constant temperatures given by the law $A + (\theta_0 - B)\left(1 - \frac{z}{l}\right)$. From this we may see, that, with a very rude approximation to a uniform gradient in the temperatures of the edge of a disk of relatively large thickness, the final temperatures on the axis are sensibly the same as for an infinite disk of the same thickness.

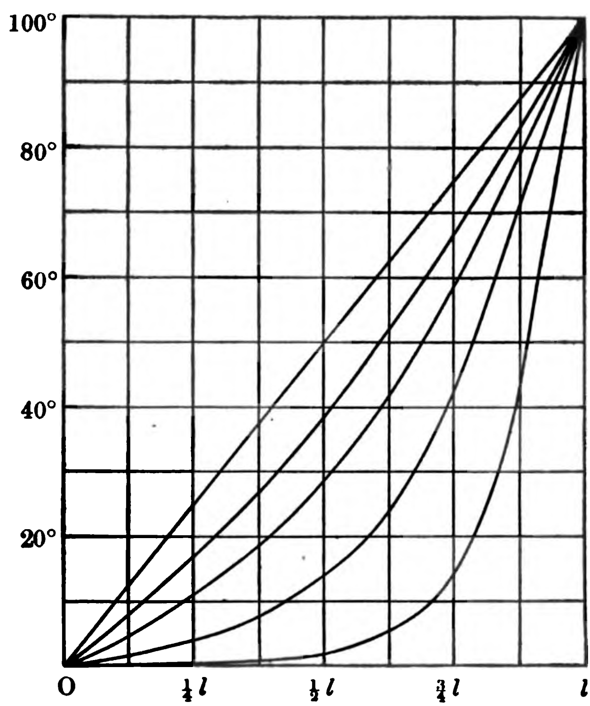

FIGURE 1.

Some of the results given in the first column of Table VII., with some others, are represented graphically in Figures 1 and 2. In Figure 1 the ordinates are the final axial temperatures; the abscissas, the distances from the cold face of the slab. The straight line corresponds to an infinite slab; the other curves, in order, to disks where $a = l$, $a = \frac{3}{4} l$, $a = \frac{1}{2} l$, and $a = \frac{1}{4} l$, respectively. In Figure 2, the ordinates of the three curves are the final temperatures on the axis at the points $z = \frac{l}{4}$, $z = \frac{l}{2}$, $z = \frac{3l}{4}$, respectively, and the abscissas are the values of a, each horizontal space corresponding to a change in a of $\frac{1}{2} l$.

TABLE VII.

Final Axial Temperatures in a homogeneous Disk of Radius a and Thickness l, when one Face ($z = 0$) is kept at 100° C., the other Face ($z = l$) at 0° C., and the Edge at the uniform Temperature $\bar{\theta}$.

a/l	z/l	$\bar{\theta} = 0°$	$\bar{\theta} = 100°$	$\bar{\theta} = 50°$
$\frac{1}{4}$	$\frac{1}{4}$	14.05	99.88	56.95
$\frac{1}{4}$	$\frac{1}{2}$	1.30	98.70	50.00
$\frac{1}{4}$	$\frac{3}{4}$	0.12	85.95	43.03
$\frac{1}{2}$	$\frac{1}{4}$	42.32	96.07	69.20
$\frac{1}{2}$	$\frac{1}{2}$	13.93	86.07	50.00
$\frac{1}{2}$	$\frac{3}{4}$	3.95	57.68	30.80
$\frac{3}{4}$	$\frac{1}{4}$	58.15	88.83	73.49
$\frac{3}{4}$	$\frac{1}{2}$	28.54	71.46	50.00
$\frac{3}{4}$	$\frac{3}{4}$	11.17	41.85	26.51
1	$\frac{1}{4}$	66.41	82.86	74.63
1	$\frac{1}{2}$	38.39	61.61	50.00
1	$\frac{3}{4}$	17.14	33.59	25.36
$\frac{3}{2}$	$\frac{1}{4}$	72.84	77.12	74.98
$\frac{3}{2}$	$\frac{1}{2}$	46.98	53.02	50.00
$\frac{3}{2}$	$\frac{3}{4}$	22.88	27.16	25.02
2	$\frac{1}{4}$	74.48	75.51	74.99
2	$\frac{1}{2}$	49.27	50.73	50.00
2	$\frac{3}{4}$	24.49	25.52	25.01
3	$\frac{1}{4}$	74.97	75.03	75.00
3	$\frac{1}{2}$	49.96	50.04	50.00
3	$\frac{3}{4}$	24.97	25.03	25.00
5	$\frac{1}{4}$	75.00	75.00	75.00
5	$\frac{1}{2}$	50.00	50.00	50.00
5	$\frac{3}{4}$	25.00	25.00	25.00

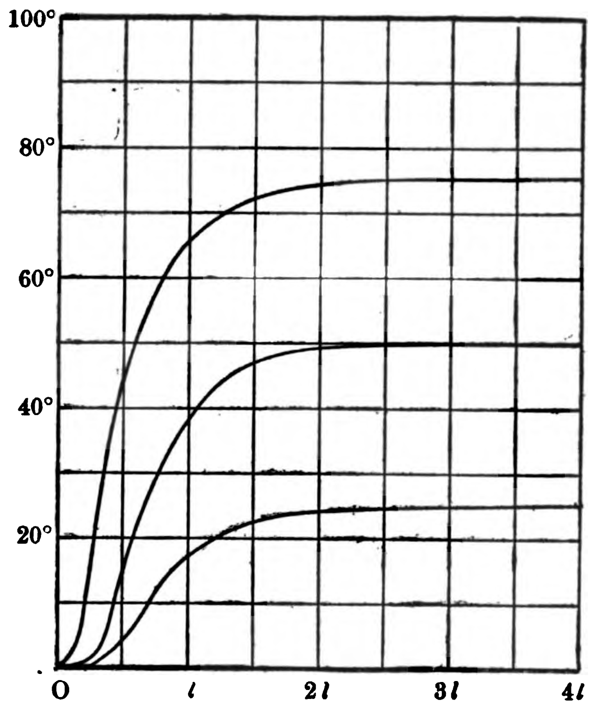

FIGURE 2.

If one is to measure the quantity of heat that passes through a portion of the disk, lying within a cylindrical surface of revolution of relatively small radius co-axial with the disk, it is desirable to make the ratio of a to l so large that possible changes in the edge temperatures shall not sensibly affect the temperatures at any point within the portion in question. It will be sufficient for our purpose to consider the temperatures at a distance l from the axis in a homogeneous disk for which $a = 5\,l$. It is evident that the greatest effect of temperature changes on the edge of the disk will apppear at those points on the inside cylindrical portion nearest the edge, that is, farthest from the axis.

Taking the formula

$$\theta = \bar{\theta}\,(1 - 2\,T_x - 2\,T_{l-x}) + 2\,\theta_0 \cdot T_{l-x} + 2\,\theta_l \cdot T_x,$$

and using the values of T given in Table VI., we see that, if $\theta_0 = 100°$ C. and $\theta_l = 0°$ C., and, if the whole edge is kept at the temperature 0° C.,

the temperature at no point within the cylinder of radius l co-axial with the disk differs by more than $0^{\circ}.02$ from the temperature at the corresponding point in an infinite disk of the same thickness and same face temperatures. In practice there is always a gradual fall in edge temperatures as z increases from 0 to l, and in such a case we may consider a guard ring of width $4\,l$ amply large enough to make the final temperatures within a right cylinder of radius l and thickness l sensibly equal to those within an infinite slab of the same thickness and same face temperatures.

In our experimental work we have sometimes found it desirable to introduce between two slabs of low conductivity a thin sheet of tinfoil of comparatively very high conductivity. It is evident that under conceivable conditions such a layer of metal might seriously affect the final temperatures in the slabs near their common axis. To investigate the disturbances that might arise from this cause, we may apply the solution of Problem 5 given above to the extreme case where the uniform edge temperature is equal to one of the face temperatures, and where $k_1 = k_3$.

If we attempt to compute numerical values of the series

$$\sum_{p=0}^{p=\infty} A_1 \,.\, J_0\left(\frac{x_p\, r}{a}\right) \,.\, \sinh\left(\frac{x_p\, z}{a}\right)$$

by using the expression for A_1 given in equation (32), we shall find the amount of labor involved enormous; we will therefore change the form of the expression so as to make the nature of its dependence upon the dimensions of the cylinders and upon their conductivities more evident, keeping in mind the fact that the ratio of k_2 to k_1 is very large. If we denote the denominator of the second member of (32) by D, and write

$$\alpha \equiv \sinh^{-1} s', \qquad \alpha + \delta \equiv \sinh^{-1} s'', \qquad \text{and} \quad \alpha_0 \equiv \sinh^{-1} s\,,$$

we have

$$\begin{aligned} D = s\,&\{(\mu\, s''^2 - c''^2)\,(\mu\, c'^2 - s'^2) - (1-\mu)^2 c'\, s'\, c''\, s''\} \\ &\qquad + c\,(1-\mu)\{s''\, c''\,(\mu\, c'^2 - s'^2) - s'\, c'\,(\mu\, c''^2 - s''^2)\} \\ = \tfrac{1}{4}\, s\,&\{(1-\mu)^2 \cosh 2\delta + (\mu^2 - 1)\,[\cosh 2\,(\alpha+\delta) - \cosh 2\,\alpha] - (1+\mu)^2\} \\ &\qquad - \tfrac{1}{4}\, c\,(1-\mu)^2 \sinh 2\,\delta + \tfrac{1}{4}\, c\,(1-\mu^2)\,[\sinh 2\,(\alpha+\delta) - \sinh 2\alpha] \\ = \tfrac{1}{4}\,&\{(1-\mu)^2 \sinh\,(\alpha_0 - 2\,\delta) - (1+\mu)^2 \sinh \alpha_0 \\ &\qquad - (1-\mu^2)\,[\sinh\,(\alpha_0 - 2\,\alpha - 2\,\delta) - \sinh\,(\alpha_0 - 2\,\alpha)]\}, \end{aligned}$$

and $A_1 =$

$$\frac{4\mu\Omega}{(1+\mu)^2\sinh\alpha_0-(1-\mu)^2\sinh(\alpha_0-2\delta)+(1-\mu^2)[\sinh(\alpha_0-2a-2\delta)-\sinh(\alpha_0-2a)}.$$

This expression, though still sufficiently complicated, shows that for properly chosen cases, as good for our present purpose as any others, the computation is comparatively simple.

If, for instance, the thickness of the lower slab is half that of the disk formed of the two slabs and the intermediate sheet of metal, $l' = \frac{1}{2} l$ and $\alpha_0 = 2a$, so that

$$A_1 = \frac{4\mu\Omega}{(1+\mu)^2\sinh\alpha_0-(1-\mu)^2\sinh(\alpha_0-2\delta)-(1-\mu^2)\sinh 2\delta} \quad (38).$$

$$= \frac{\Omega}{\sinh\alpha_0\left\{1-\frac{(1-\mu)^2}{2\mu}\sinh^2\delta+\frac{(\mu-1)\sinh^2\delta}{4\mu\sinh\alpha_0}[1-\cosh\alpha_0+\mu(1+\cosh\alpha_0)]\right\}}, \quad (39)$$

If we denote the denominator of this expression by $\sinh\alpha_0 \,.\, (1+\Delta)$, and note that, if we make μ equal to unity, we shall have $A_1 = \frac{\Omega}{\sinh\alpha_0}$, corresponding to the case of a homogeneous cylinder already treated in Problem 4, we shall see that V_1 in the case of the heterogeneous cylinder can be found by multiplying each term of the series for T_z by the quantity $\frac{2V_l}{(1+\Delta)}$, and that in our problems the resulting series is usually more convergent than the original.

In order to exaggerate the magnitude of the disturbing effect of the tinfoil, we have chosen for computation a value of μ much smaller and a value of δ much greater than the proper values of these quantities for most of our experiments, assuming that $a = 5l = 10l' = 500(l'' - l')$, and that $\mu = 0.002$, so that Δ is nearly equal to

$$\tfrac{1}{2}x_p\tanh\tfrac{1}{2}\alpha_0 - \frac{x_p}{1000}\operatorname{ctnh}\tfrac{1}{2}\alpha_0 - \frac{x_p^2}{1000}, \quad \text{where} \quad \alpha_0 = \frac{x_p}{5}.$$

These values correspond in certain cases to large disturbances of temperature on the axis of the slabs, as the results show. Consider, for instance, the point $z = l'$, $r = 0$, in a compound slab 2 cm. thick and 20 cm. in diameter, built up of a slab of poorly conducting material 1 cm. thick, a sheet of metal 0.2 mm. thick, and a second slab of the same material as the first. Let the lower face be kept at the temperature 0° C., the other face at the temperature 100° C., and let every point of the edge be kept

at 0° C. The terms of the series which give the final temperature may be found without much difficulty by the aid of the numbers in the third column of Table V. Their values are

1.	+61.3980
2.	−19.6480
3.	+ 7.8876
4.	− 3.7116
5.	+ 1.8474
6.	− 1.0224
7.	+ 0.5938
8.	− 0.3568
9.	+ 0.2198
10.	− 0.1382
11.	+ 0.0882
12.	− 0.0570
13.	+ 0.0372
14.	− 0.0246
15.	+ 0.0162
16.	− 0.0110
17.	+ 0.0074
18.	− 0.0050
19.	+ 0.0034
20.	− 0.0022

etc., so that the temperature required is 47°.12+ C.

The terms of the series which give the final temperature at points for which $z = 1$, $r = 2$, can be found in a similar way by the help of the numbers in the third column of Table VI. Their values are

1.	+57.8982
2.	−14.1020
3.	+ 2.9988
4.	− 0.0904
5.	− 0.4716
6.	+ 0.4020
7.	− 0.2192
8.	+ 0.0782
9.	− 0.0018
10.	− 0.0254
11.	+ 0.0256

12.	$-$ 0.0160
13.	$+$ 0.0062
14.	$-$ 0.0000
15.	$-$ 0.0024
16.	$+$ 0.0026
17.	$-$ 0.0018
18.	$+$ 0.0008
19.	$-$ 0.0000
20.	$-$ 0.0002

and the temperature is 46°.48.

If the radii of the slabs and the metal sheet had been infinite, the temperature in these media would have been given by the expressions Mz, $M(\mu z + 1 - \mu)$, and $M(z + \frac{1}{50}(\mu - 1))$, respectively, where $M = 100 / (1.98 + .02\,\mu)$. In all practical cases the temperatures of points on the rim of the disk increase gradually from the cold face to the warm face, and it would be easy to show that those portions of the isothermal surfaces which we have used in computing the results of our observations are sensibly plane.

The characteristic differential equation which gives the relation between the temperature, the space co-ordinates, and the time in a body in which there is an unsteady flow of heat, involves the specific heat of the body, which is itself a function of the temperature. Without attempting just here to investigate the nearness of the approximation obtained in any given case by assuming the specific heat to be constant, we will give for future reference some numerical results obtained by using several different values of z, t, and c in the solution of Problem 3.

An infinite homogeneous lamina of thickness l is originally at the temperature $c\,V_0$ throughout. From a given time, $t = 0$, one face is kept at the constant temperature V_0, and the other face at the temperature 0°. The ratio of the conductivity of the slab to its specific heat is to be denoted by the constant a^2, the ratio of l^2 to $a^2\pi^2$ by T, and the distance of any point in the lamina from the face which is kept at the temperature V_0, by z.

The numbers in Table VIII. show the rate of flow across the cold face of the lamina in fractional parts of the final rate for different values of c and t, while the numbers in Table IX. give the rate of flow across different planes parallel to the lamina faces at different times, for the special case $c = \frac{1}{4}$.

TABLE VIII.

	$t=\frac{1}{8}T$	$t=\frac{1}{4}T$	$t=\frac{1}{2}T$	$t=T$	$t=2T$	$t=4T$	$t=6T$
$c=-1$	–5.013	–3.544	–2.434	–1.171	0.188	0.890	0.986
$c=-\frac{1}{2}$	–2.506	–1.772	–1.199	–0.435	0.459	0.927	0.990
$c=-\frac{1}{4}$	–1.253	–0.886	–0.582	–0.067	0.595	0.945	0.993
$c=0$	0.000	0.000	0.036	0.301	0.730	0.963	0.995
$c=\frac{1}{4}$	1.253	0.886	0.654	0.669	0.865	0.982	0.998
$c=\frac{1}{2}$	2.507	1.773	1.271	1.037	1.001	1.000	1.000
$c=1$	5.013	3.545	2.507	1.773	1.271	1.037	1.005

TABLE IX.

	$t=\frac{1}{8}T$	$t=\frac{1}{4}T$	$t=\frac{1}{2}T$	$t=T$	$t=2T$	$t=4T$	$t=6T$
$z=0$	3.760	2.659	1.889	1.405	1.136	1.018	1.002
$z=\frac{1}{8}l$	2.762	2.279	1.756	1.366	1.125	1.017	1.002
$z=\frac{1}{4}l$	1.095	1.438	1.420	1.260	1.096	1.013	1.002
$z=\frac{3}{8}l$	0.235	0.682	1.030	1.115	1.051	1.007	1.001
$z=\frac{1}{2}l$	0.036	0.301	0.730	0.963	0.999	1.000	1.000
$z=\frac{5}{8}l$	0.082	0.278	0.587	0.823	0.948	0.993	0.999
$z=\frac{3}{4}l$	0.365	0.489	0.578	0.740	0.904	0.987	0.998
$z=\frac{7}{8}l$	0.922	0.761	0.627	0.686	0.876	0.983	0.998
$z=l$	1.253	0.886	0.654	0.669	0.865	0.982	0.998

In Figure 3, the abscissas are the elapsed times (one division $= \frac{1}{8}T$), and the ordinate corresponding to any abscissa is the rate of flow of heat at that instant across every unit of surface of the cold face of the lamina

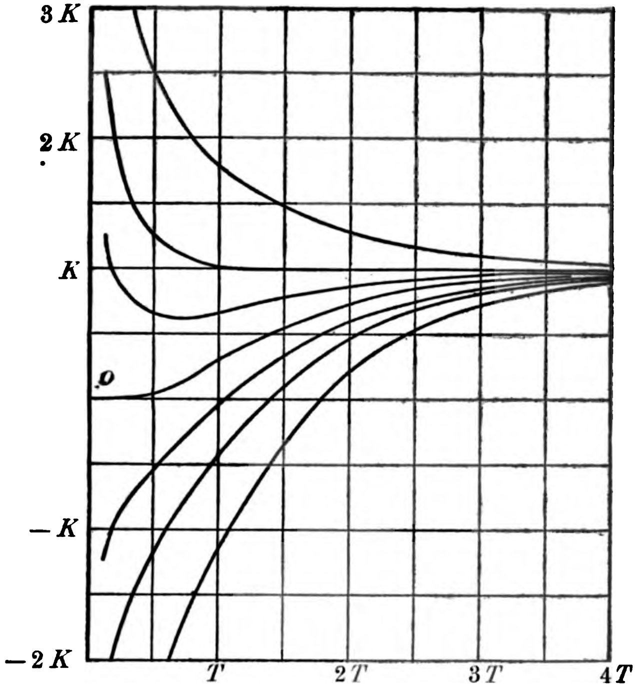

FIGURE 3

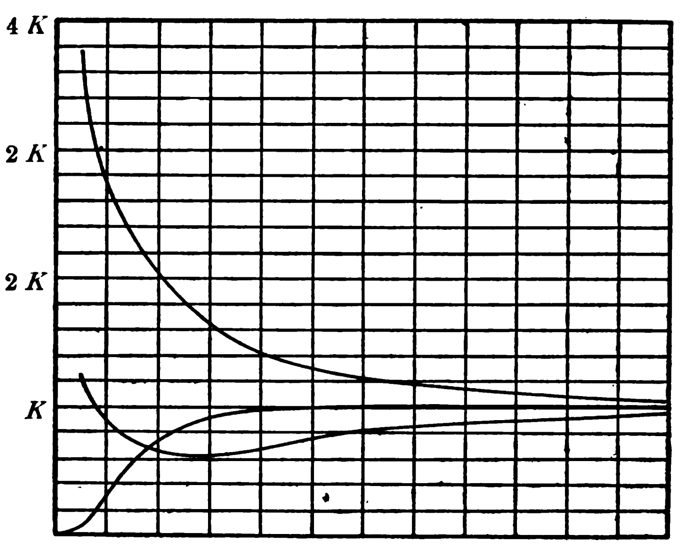

FIGURE 4.

(one vertical division $= \frac{1}{2} \kappa V_0 \div l$). Every curve corresponds to a particular value of c, and the values represented are 1, $\frac{1}{2}$, $\frac{1}{4}$, 0, $-\frac{1}{4}$, $-\frac{1}{2}$, -1, respectively. All the curves have, of course, the common asymptote, $y = \kappa V_0 \div l = K$, where K is the final rate of flow.

If V_0 is to be 100° C., and the slab is to be originally at room temperatures, we may put $c = \frac{1}{4}$. The ordinates of the curves in Figure 4 represent the flow of heat, when $c = \frac{1}{4}$, across the hot face, the cold face, and the plane midway between them, at the times indicated by the abscissas. The horizontal unit is $\frac{1}{4}$ T, the vertical unit $\frac{1}{5} \frac{k V_0}{l}$.

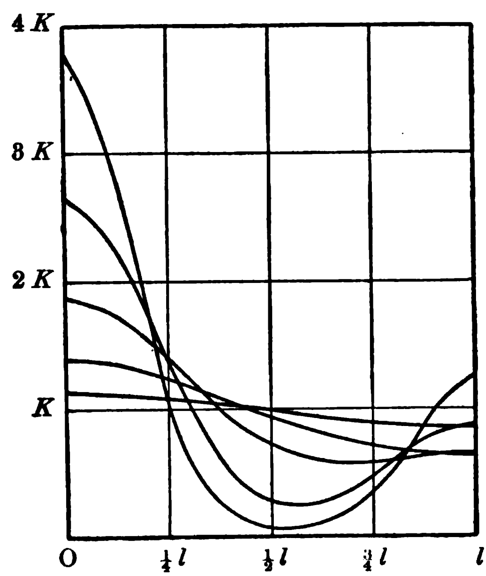

FIGURE 5.

In Figure 5, the abscissas are values of z, the ordinates are rates of flow. Each curve corresponds to a given epoch, and the epochs represented are $\frac{1}{8} T$, $\frac{1}{4} T$, $\frac{1}{2} T$, T, $2T$.

Without waiting to discuss here certain theoretical questions which will present themselves in the course of our work, we may briefly describe some preliminary experiments.

We have used two different forms of apparatus in our work, the one intended for measuring the absolute thermal conductivities at tempera-

tures between 0° C. and 100° C. of relatively poor conductors like plates of stone or glass; the other designed merely for comparing the conductivities of slabs which form a prism or "wall," through which there is a steady flow of heat.

Of this second form of apparatus, which is much simpler than the other, we have three of different sizes for plates 65 cm., 35 cm., and 20 cm. in diameter respectively. Rough diagrams which show the essential parts of two of these, without their elaborate stands and jackets, are given in Figures 6 and 7. In each, the prism to be tested is enclosed

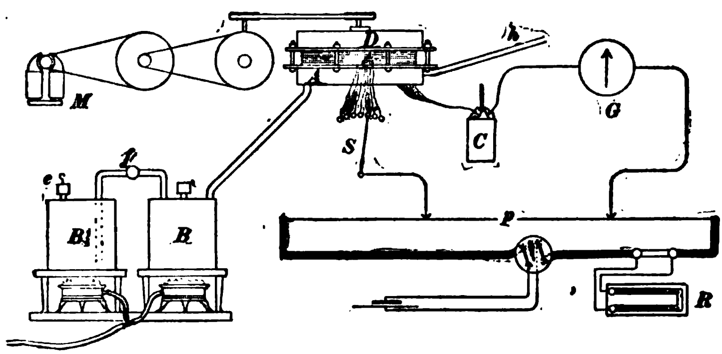

FIGURE 6.

between the horizontal planed plates of two castings, which are fastened firmly together by bolts around their edges to insure close contact with the body under experiment. Both castings are hollow; one forms a jacketed chamber through which steam or mercury vapor may be passed for an indefinite period. The upper casting, which is provided with a system of stirrers or scrapers operated by an electric motor, may be kept at a low temperature by filling it with ice or by sending through it a steady stream of water from a very large tank within the tower of the laboratory.

In Figure 6, A represents the hot chamber, weighing about two hundred kilograms, which rests in a thick jacket on a heavy table or stand made to hold it. A is connected directly with one (B) of two stout-walled copper boilers, B and B', each of which holds about 40 litres of water. A light cup-shaped weight, inverted and laid on a large tube with squared end which projects above the top of the boiler, acts as a sensitive safety valve and prevents any appreciable rise in temperature within the boiler. B can be refilled when necessary with boiling water

from *B'* without stopping the constant flow of steam through *A*, by means of the siphon *f*, which is provided with a valve. The steam, after passing through the hot chamber, is led to the outer air by a jacketed pipe *h*, descending * from the bottom of *A*.

The connections of the thermal elements are led out of the sides of the prism shut in by *A* and *D*, and are held between slabs of wood, which act as a sort of guard-ring jacket to the prism for about 40 centimeters before they emerge. The platinoid or German silver leads of these thermal junctions within the prism are soldered together, and to a copper wire leading to the (copper) wire of a potentiometer, *p*. The copper ends of the couples lead to a mercury switch by which any one of them, or any pair pitted against each other, may be quickly connected with a second copper wire leading to the potentiometer. On its way from the switch to the cold junctions in *C* through the potentiometer wire, the current encounters only copper. By means of a somewhat elaborate standard potentiometer, not shown in the diagram, the resistance, *R*, in the potentiometer circuit can be so adjusted that every millimeter on the potentiometer wire corresponds to any desired small potential difference, such as one microvolt or one tenth of a microvolt. Rather than make this adjustment many times a day to conform to the varying temperature of the copper wire, however, we find it better to determine the slight corrections necessary to reduce the readings to absolute measure, by noting at frequent intervals the indications of a standard thermal couple, the electromotive force of which is well known. The potentiometer wire, which is 0.25 mm. in diameter, can be changed in a few seconds for new wire, if the old should become dented or stretched.

Into the vessel *D* about 100 kilograms of cracked ice can be put, and this ice can be kept in constant motion over the smooth bottom by help of the electric motor, *M*.

Figure 7 shows a similar but smaller apparatus without its elaborate system of inch thick asbestos jackets. *D* is a closed iron drum containing a rotary stirrer and rubber scraper turned by a motor. Through *D* a large volume of water can be sent at a steady rate. The hot chamber is the iron box, *B*, planed on its upper surface and communicating at the bottom with a retort chamber, *C*, in which about 20 kilograms of mercury can be kept boiling. The outlet at *f* allows the vapor to escape to the tube *g*, connecting with a large wrought iron chamber where it condenses

* In the diagram, *h* is erroneously represented as *ascending*, and as inserted in the side of *A*.

and flows back into the retort through the trap h. This apparatus takes slabs 35 centimeters square. Although we found it possible to maintain with this arrangement a temperature above 350° C., for many hours at a time, it was difficult to avoid superheating by conduction through the massive iron of the hot box, and we intend to discard mercury in future and use some less troublesome source of heat. If a substance of greater heat of vaporization than mercury is employed, the retort can be removed to such a distance that all danger of superheating is removed. We have not yet been able to test an electrical stove which we hope may prove to be a convenient and a sufficiently constant source of heat for many purposes.

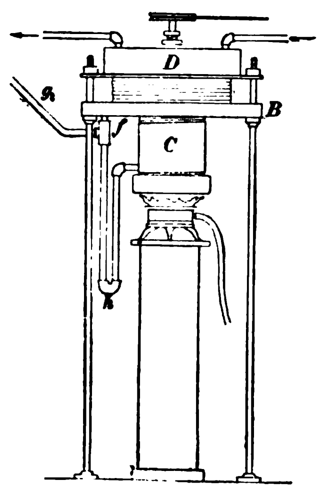

FIGURE 7.

The apparatus just described has been furnished with trunnions so that the axis of the prism can be made horizontal or vertical at pleasure. This renders it possible to use a layer of mercury on each side of the slab to be tested, when this is desirable.

Our third apparatus of this kind is made entirely of brass. It is intended only for small thin plates about 20 cm. in diameter, but is in essentials like the apparatus just described.

Figure 8 represents the apparatus which we have used to determine the absolute conductivities at temperatures between 0° C. and 100° C. of various materials. The boilers and the hot chamber are those of the apparatus shown in Figure 6; the ice box, which is the outcome of

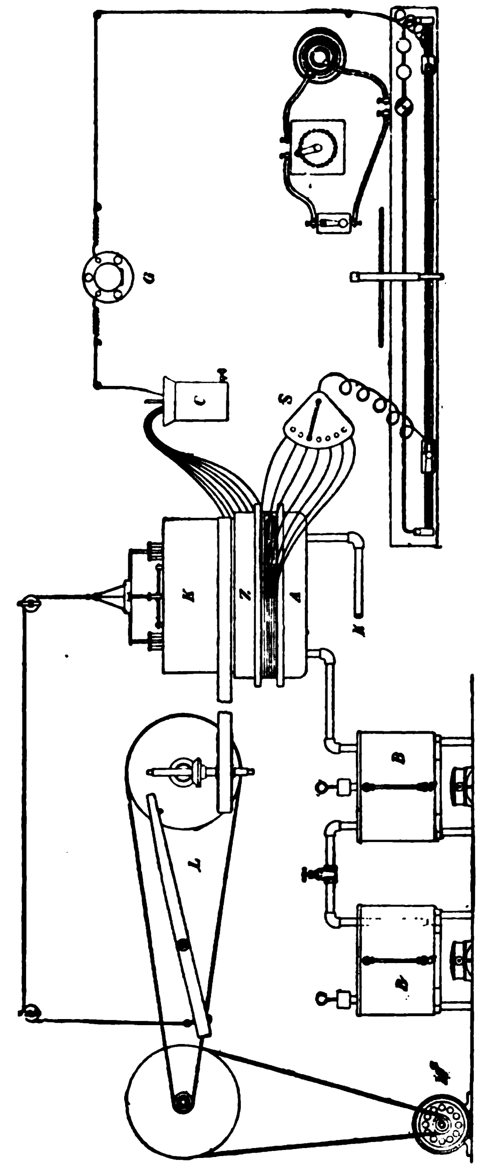

Figure 8.

several years of experimentation, is entirely different. An iron casting, Z, seen in plan in Figure 11 and in elevation in Figure 9, accurately planed below and turned true above, is the bottom of the box. Between this casting (which can be bolted to A as D is in Figure 6) and

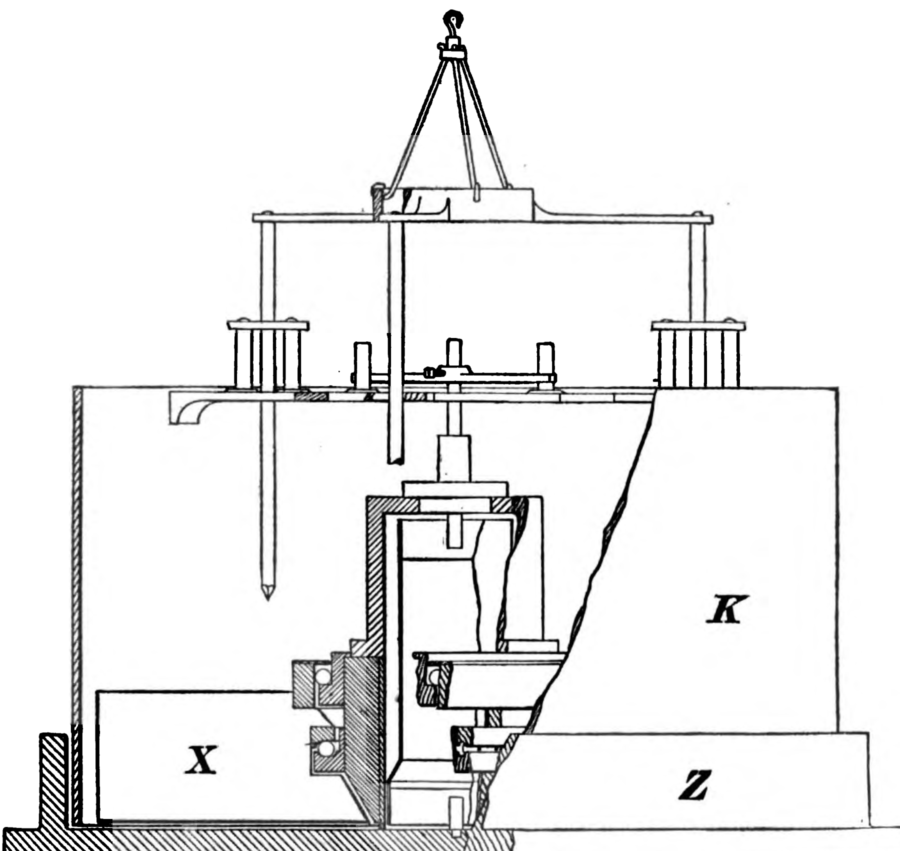

FIGURE 9.

A is held the prism to be experimented on. While Z was in the lathe a small hole, H, about 3 millimeters in diameter and 4 millimeters deep was drilled exactly in the centre of its upper face. Subsequently a piece of solid drawn brass tube 12.3 cm. in outside diameter and 13.5 cm. high, with carefully squared ends, was held centrally in Z, by means of a

wooden disk turned to fit it, and a central pin inserted in H, and was then soldered firmly to Z. This was accomplished, after many trials of other materials, by the use of white pitch as a flux, and the result left nothing to be desired. The walls of the pot thus formed were jacketed on the outside, except for a height of about 2 millimeters at the bottom, by an inch thick casting of hard rubber made for the purpose in the form of a cylindrical shell. This casting, which was cut off square at the top of the pot, tapered to nothing near the bottom, but did not rest upon the floor. (Figure 10.) Upon the top of this jacket was fastened a hard rubber cover shaped somewhat like a cylindrical hat. This had an opening at the top which could be closed by an accurately fitting rubber plug. In the box P, thus made, is placed a thin-walled ice holder, Q, open at top and bottom, of the same outside diameter below as the inside of the brass pot, but somewhat smaller above, so as to leave an air space between it and the walls of the pot.

In order that the holder may be easily rotated, a pin soldered to a thin diametral web, F, which runs across the bottom of the holder, is inserted in H, and a vertical brass rod soldered to a similar web, E, at the top of the holder passes through a hole in the corner of the pot which it fits closely. A hard rubber thimble fitting tightly on the rod and turning with it permits the slow entrance of cold air into the pot without allowing any water to leak in. The rod can be clamped at pleasure to a brass yoke which is turned by the motor. In order to prevent the introduction of heat into the pot by conduction down the rod, the exposed portion is buried in cracked ice held in a thin metallic cup carried by the yoke and resting on it. When the holder is filled with ice and is turned by the motor, the web at the bottom compels the ice to rub over the floor of the casting, since the holder itself has no bottom, and as a result of this, the lower surface of the ice quickly acquires and keeps a mirror-like surface. The drip from the pot comes out of the edge of the casting Z through a straight hole about 26 cm. long and 0.6 cm. in diameter drilled in the plate and ending just inside the pot. The whole apparatus is very slightly tilted so as to insure the steady outflow of the drip.

A large cylinder, K, 35 cm. high, made of rolled brass 4 mm. thick and open at the top and bottom, is mounted on brass ball bearings placed on the outside of the hard rubber jacket of the pot P, by means of six vanes, one of which, X, is shown in Figure 9. K weighs about 20 kilograms when empty, and rests upon 144 brass balls each about 12 mm. in diameter. When set in motion by a slight push, it continues to rotate

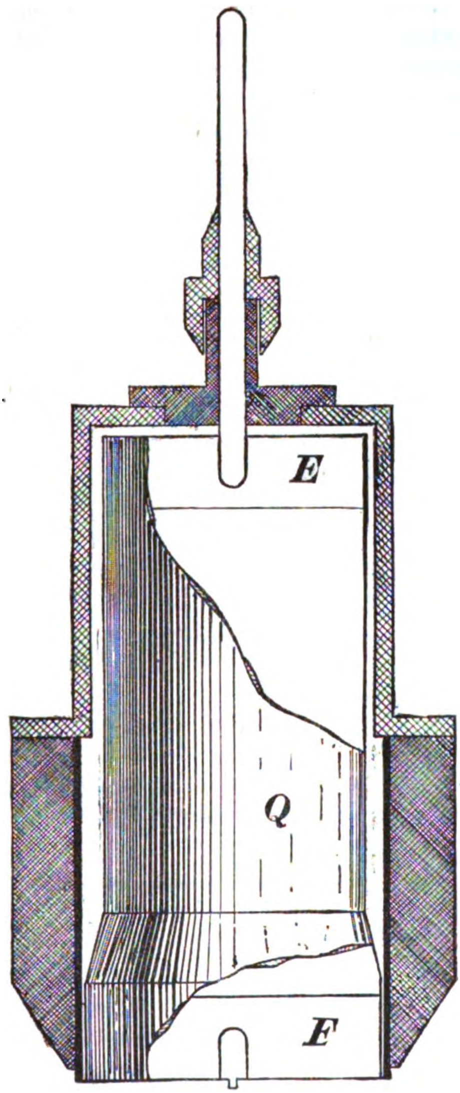

FIGURE 10.

for about a minute before coming to rest. This, like most of our other apparatus, was constructed by Mr. G. W. Thompson, the mechanician of the Jefferson Laboratory, and we have been much indebted to his skill and patience at every stage of our work. *K* is so truly hung that the outside can be used as a pulley and the whole can be rotated by the use of the belt shown in Figure 8. The vanes reach to about 2 millimeters

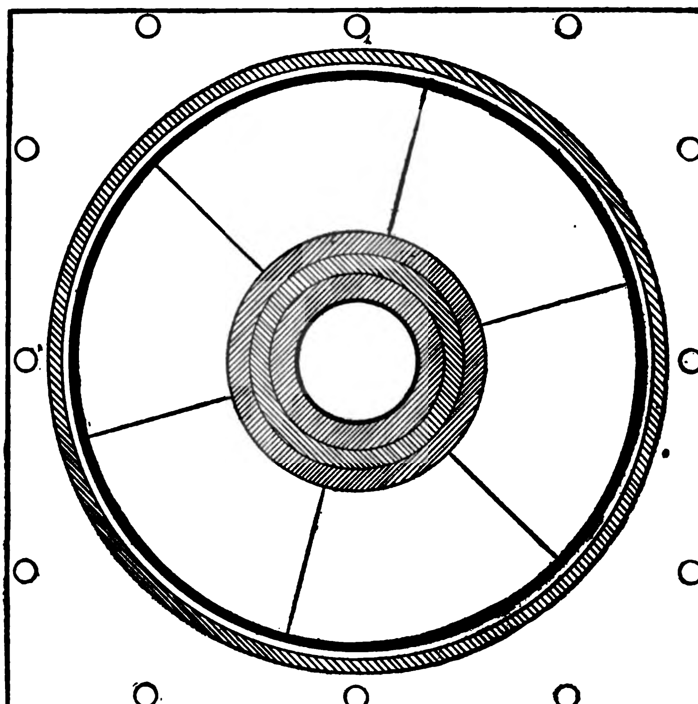

Figure 11.

of the floor of the box, and when the whole is filled with cracked ice and then rotated, the ice at the bottom which rubs on *Z* soon gets and holds a very smooth surface. A hole in the bottom of *Z* carries away the drip and prevents any accumulation of water on the floor of the ice box. We were at first troubled by irregularities arising from honeycombing of the ice in the ice box, and to remedy this a suitably loaded brass tripod is used to pack the ice by light blows delivered at intervals of 21 seconds, by the aid of the lever *L*. A train of four wheels is necessary to reduce the

speed of K to one revolution in 20 seconds, though only two wheels are shown in the drawings. The tripod slides in guides which revolve with K, and a swivel at the top prevents the cord from twisting.

The rotation of K and of the inside ice holder, Q, which is connected with K by a thin yoke, are matters of much importance. The continual rubbing of the ice over the flat surface of the casting seems to be necessary if the latter is to be kept at a uniform constant temperature for hours. The energy used in rotating Q is so little as to be quite negligible, as we shall show further on. The ice in K is piled up so as to cover P completely, and we have been unable to detect any difference between the temperatures within and without P by fine, properly protected thermal junctions introduced for the purpose. If, while K revolves, Q is kept still, the amount of ice melted in Q becomes irregular, though the whole amount of drip in two or three hours is not very different from the amount of steady drip in an equal time when Q is rotating. Only selected lumps of ice are put into Q. The ice to be used is first broken up into pieces weighing something like 15 grams each, by means of an ice-cracking machine, and these pieces are then put into ice water so that their sharp edges may become slightly rounded. They are then drained and dropped into Q. In this way a slight amount of water attached to the ice is introduced into Q, but the error due to this cause appears to be of slight importance. In some of our experiments the ice to be used was carefully dried in cold blotting paper, but this precaution does not seem to be necessary, though the use of small bits of ice with sharp edges is to be avoided. Q's capacity is about 2,000 cubic centimeters. After Q has been freshly filled in the course of any experiment while K is rotating, no record is kept for some time, perhaps fifteen minutes, of the amount of drip. Before the expiration of this interval the extra water introduced into Q with the ice has drained off, and the indications have become steady. After this the apparatus is allowed to run for about two hours until 300 grams of ice or less has been melted, and then Q is refilled. The drip tube always contains a few drops of water, but this amount remains sensibly constant during the progress of our experiment. The drip is collected in a graduated vessel, and the approximate amount is noted from time to time to see whether the flow is steady. The whole is then more accurately determined by weighing, at longer intervals.

The regularity of drip is a far more sensitive test of the approximate attainment of the final state of the body experimented on and its surroundings than is a sensibly constant temperature gradient on the axis.

In most of our experiments with the large apparatus just described, a sufficiently steady state has been attained in about five hours from the beginning of the heating. Sheets of blotting paper were generally inserted between the prism to be tested, and the hot and cold boxes, to serve as elastic pads, and to prevent the possible wetting of the edge of the prism by moisture condensed on the ice box. The presence of this paper prolonged the time of waiting for the final state to be attained, but did not influence the results of the measurement of the conductivity of the prism. When filled with ice, Z and K weigh about 300 kilograms, and the additional pressure due to the bolts is considerable, so that, when the prism is made up of brittle material like glass, the blotting paper or an equivalent must be used to prevent the prism from injury. We have tried several different materials, and of these the blotting paper is the most satisfactory. We may note in passing, however, that the indications of thermal couples placed between soft pads and the hard prisms are often very anomalous, two thermal junctions placed side by side sometimes differing very widely. In all the experiments that we regard as trustworthy the slab to be tested with its attendant thermopiles was placed between two other slabs *of the same material*, in forming the prism.

Most of our mercury thermometers were made by Alvergniat, or by Richards & Co., but our final standard was Tonnelot No. 11,142, upon which a very complete set of tests has been made at the International Bureau of Weights and Measures.

For temperatures higher than 100° C. we had two platinum thermometers of the general form described by Messrs. Griffiths and Callendar. These served an excellent purpose, though the wire, about 0.2 mm. in diameter, seemed from the form of the calibration curve not to be very pure. The resistance of one of them, as measured by a Carey Foster Bridge was about 29.25, 36.78, 42.85, 45.31, or 55.43 ohms, according as it was immersed in melting ice or the vapor, at 760° c.c. pressure, of water, anilin, naphthalin, or mercury. We have another thermometer made of pure platinum wire furnished by Messrs. Johnson and Matthey, 0.005 inch in diameter. This we intend to make our standard.

All our thermal elements were made either of platinoid and copper, or of German silver and copper; some were of wire, and some of narrow ribbon carefully rolled for our use. Each specimen of platinoid or German silver was "butt-jointed," generally by silver solder, to a piece

of the purest obtainable copper of equal cross section. Our finest wire thermal elements, less than one tenth of a millimeter in diameter, were so skilfully made by Mr. Sven Nelson, of Cambridge, that the joint was hardly perceptible. Our German silver and copper ribbon thermal elements, about one eighth of a millimeter thick, were made by Mr. T. W. Gleeson of Boston. These last were first soldered with the help of a holder constructed for the purpose, and the joint was then rolled or scraped until it was as nearly as might be of the same thickness as the adjacent metal.

For wire thermal elements we had large quantities of three kinds of platinoid, approximately 0.74, 0.30, and 0.097 mm. in diameter. The first two specimens were obtained about ten years ago from Messrs. Elliott Brothers, and have been thoroughly seasoned. Each is thermo-electrically pretty definite, though the two are quite different in their properties. The electromotive force, in microvolts, of platinoid and electrolytically deposited copper elements made of these wires may be tabulated as follows for low temperatures.

Temperatures of the Junctions.	Electromotive Force of Platinoid No. 1 *vs.* Copper.	Electromotive Force of Platinoid No. 2 *vs.* Copper.
0° and 10°	189	152
0° and 20°	379	306
0° and 30°	572	465
0° and 40°	769	628
0° and 50°	971	799
0° and 60°	1179	973
0° and 70°	1391	1159
0° and 80°	1609	1356
0° and 90°	1834	1569
0° and 100°	2063	1787

Besides platinoid we have used with copper for wire thermal elements two kinds of German silver wire respectively about 0.1 mm. and about

0.58 mm. in diameter. The smaller German silver wire was connected with the corresponding copper wire by a thin joint of electrolytically deposited copper. These joints were very satisfactory, but extremely tedious to make.

In some of our experiments we used fine wire thermal junctions inserted in shallow grooves accurately cut in the faces of the slabs to be tested. These grooves were made in a Brown and Sharpe Universal Milling Machine by extremely thin hard steel saws (No. 34 B. & S. Gauge) held between flat disks of somewhat smaller diameters than the saws to prevent buckling. The wire that we used fitted the grooves very closely and we hoped that the indications of the thermal couples would enable us to determine the mean temperature of the walls of the groove when the grooved slab was placed against a flat one. We soon found, however, that the results were most irregular, and, although we have spent some time in attempts to make observations obtained in this way trustworthy, we have met with little success. Sometimes our results have been good, and sometimes they have been considerably in error. We do not yet know how to make them always good. It appears that a thermal junction must be pressed firmly against a surface, the temperature of which it is to take approximately. Although we are not ready to discuss this subject exhaustively, we mention our experiences to show why we have abandoned for the present this very obvious manner of inserting thermal junctions into a prism built up out of slabs, in favor of what at first sight seems a less satisfactory device. After some preliminary experiments with fine wire thermal junctions laid between the slabs, with and without sheets of tinfoil at the sides of the wire, we determined to use the thin ribbon thermal junctions, elsewhere described, with varnished edges, so that sheets of tinfoil of the same thickness might be laid at the sides of the ribbon, and in this way a sheet of metal be introduced between the slabs.

It has been necessary for us to calibrate in the course of our work a large number of thermal elements. Some of these when properly protected we have heated with thermometers in elaborately jacketed air baths or in tanks of water or oil, and some in vapor baths. We have had considerable quantities of nearly pure chloroform, benzol, æthylen bromide, bromoform, anilin, paratoluidin, naphthalin, chinolin, *a* naphthol, acetanilid, naphthylamin, diphenylamin, phenanthren, anthracen, and a few other substances, the boiling points of which divide the ordinary thermometric scale below the boiling point of sulphur into small intervals. A good number of these, but not all, we have actually used.

Some of our thermopiles have been calibrated for us at temperatures between 0° C. and 100° C. by Mr. C. G. Persons of the staff of the Jefferson Laboratory, and he has assisted us in much of our other work.

The Thermal Conductivity of Marble.

With the apparatus described in this paper we have made a large number of experiments. As has been already intimated, we are not entirely satisfied with the source of heat that we have used for temperatures higher than 300° C. because of the difficulty of keeping these temperatures constant for long intervals of time, while for temperatures between 0° C. and 100° C., it has been easy to get closely agreeing results many times over. We have, nevertheless, made a good many determinations at the higher temperatures, and, while we are not yet ready to state definitely the law of variation with the temperature of the thermal conductivities of materials in which we have found such variations, we may say that, of the substances which we have examined, two, a special brand of glass of which we have a number of large plates, and dry white marble,* show no appreciable change in thermal conductivity within the limits of our measurements. We shall therefore content ourselves in this preliminary paper with giving the results of a number of determinations, made at different low temperatures, of the conductivities of about twenty specimens of marble of different kinds. Incidentally we shall need to describe very briefly some experiments upon the glass plates just mentioned.

It will appear that the conductivity of a specimen of marble at ordinary mean temperatures may depend to the amount of several per cent, as Messrs. Herschell and Lebour have shown, upon the amount of moisture which the specimen holds. For this reason we have aimed at an accuracy of only 1% in the determinations here recorded. A change in conductivity much less than this was of course easily observable. The difference of temperature between two thermopiles, one of which is only a few degrees hotter than the other, can be measured with considerable accuracy, but it will be sufficient here to state the results correct to tenths of degrees.

* The conductivity of the specimen of marble upon which R. Weber has made a set of extremely accurate measurements appears to change by only one two-thousandth part of its own value between 0° C. and 100° C.

While it takes a long day to make an accurate determination with our large apparatus of the absolute conductivity of a slab, two determinations may easily be made in the same time of the relative conductivities of the slabs which go to form a prism, since the gradient on the axis of the slab does not sensibly change after four hours of heating, and it is then only necessary to note the readings of the thermopiles. With our smallest apparatus and thin slabs two hours are often sufficient for a measurement. Our experience seems to show that this method of comparison is susceptible of great accuracy. We have made a very large number of direct determinations of the conductivities of different slabs of stone, but, in view of the fact mentioned above that the amount of moisture in the stone affects the conductivity very appreciably, even if the less tedious method of comparison were not equally accurate, we should think it wise in future to determine with great care the absolute conductivity of a standard substance unaffected by moisture, and then compare with it the conductivity of the stone slabs. The accuracy with which the comparison can be made is greater of course than that of a single absolute determination.

The particular kind of glass which we have found useful as a comparison substance was selected some years ago from the stock of the Boston Plate Glass Company. The faces of each plate are very nearly plane, but the planes are not in every specimen quite parallel. The conductivities of different plates are somewhat different, but the conductivity of each plate remains sensibly constant within large ranges of temperature. Cut from this glass we have a number of slabs 60 centimeters square, a number of slabs 30 centimeters square and some disks about 20 centimeters in diameter.

We shall wish to discuss the properties of this kind of glass at higher temperatures more particularly on another occasion. For our present purposes, it is worth while to measure the temperatures to tenths of degrees only and the thickness of a slab to the nearest twentieth of a millimeter, and an account of a few experiments to this degree of accuracy, chosen almost at random from the large number of which we have records, will suffice.

Slabs A, B, C, and D are cut from one particular large homogeneous piece of this glass, the conductivity of which, according to our determinations, is to that of Plate III. mentioned below as 187 to 175. We shall assume the conductivities of these slabs to be 0.00277 at all ordinary temperatures. We have not been able to detect any differences in their conductivities.

Experiment (*a*). A compound slab, made up of slabs *B* and *A* with their thermal elements, was placed between two other glass plates to form a prism. The thickness of *B* is 0.950 cm. and of *A* 0.935 cm. In the final state of the prism, the thermal elements on the warmer face of *B*, between *B* and *A*, and on the colder side of *A*, indicated 88°.1, 63°.4, and 38°.9 respectively. A fall of 14°.7 in 0.950 cm. is very nearly equal to a fall of 14°.5 in 0.935 cm.

Experiment (*b*). In the final state of a prism made up of slabs *A* and *B* shut in between two other glass plates, the thermal elements on the warmer face of *A*, between *A* and *B*, and on the colder face of *B*, indicated 85°.0, 62°.2, and 39°.1 respectively. A fall of 22°.8 in 0.935 cm. is very nearly equal to a fall of 23°.1 in 0.950 cm.

Experiment (*c*). Three slabs *A*, *C*, and *E* of the standard glass with three other glass plates, which we may denote by *P*, *Q*, and *R*, were built up into a prism *P A Q C E R* with thermal elements between *P* and *A*, *A* and *Q*, *Q* and *C*, *E* and *R*. In the final state the temperatures of the thermal elements were very nearly 88°.2, 74°.2, 58°.8 and 30°.0, respectively, so that the gradient in the slab *A* of thickness 0.935 cm. is almost exactly the same as in the double slab *C E* of thickness 1.93 cm. There seemed to be, therefore, no appreciable contact resistance (Uebergangswiderstand) between the two slabs.

Experiment (*d*). After experiment (*c*) had been finished, a narrow ring of blotting paper, the inside diameter of which was only slightly less than the diameter of the disks, was inserted between *C* and *E* so as to have a dead air space between them 0.7 mm. thick, when the prism was under pressure. In the final state the temperatures were now 89°.9, 78°.3, 66°.5, and 25°.9, so that in this particular case the dead air space was nearly equivalent to a glass plate 4.8 mm. thick.

Experiment (*e*). In this experiment Plate III., of 0.875 cm. thickness, was a part of a prism heated in the larger apparatus intended for the determination of absolute conductivities. The temperatures of the thermal elements on the faces of the plates in the final state were 69°.7 and 58°.8 respectively. In 9060 seconds 464.5 grams of ice were melted. Assuming the area of the bottom of the ice pot to be 126.7 square centimeters and the latent heat of melting of ice to be 79.25, this corresponds to a conductivity of 0.00258. It is obvious, however, that the last figure of this number is not quite definitely determined.

Experiment (*f*). In the final state of a prism similar to the one used in the last experiment, 311.9 grams of ice were melted in 5340 seconds when the temperatures of the thermal elements on the faces of Plate III. were 66°.4 and 54°.1. This corresponds to a conductivity of 0.00260. Here again the last figure is in doubt.

We had occasion to measure the absolute conductivity of only one other of the 60 cm. square plates bought at the same time as Plate III. This was Plate I. The results of two experiments made on it were 0.00262 and 0.00259. The crown glass used by Oddone had a conductivity of 0.00245, that of Lees * a conductivity of 0.00243.

We will next cite a single experiment to show how much the conductivity of the particular kind of statuary marble that we used could be changed by moistening the stone.

Experiment (*g*). A prism was made up of three plates of glass, *A*, *P*, and *Q*, and three dry slabs of statuary marble, *C*, *D*, and *E*, arranged in the order *P A Q E D C* with thermal junctions between *P* and *A*, *A* and *Q*, *E* and *D*, *D* and *C*. The temperatures indicated by the thermal junctions when the prism had sensibly reached its final state were 84°.6, 67°.7, 38°.6, and 27°.7. *D* was then well moistened with water, and the experiment was then repeated. The temperatures were then 85°.3, 70°.5, 46°.0, and 38°.1, so that the conductivity of *D* had been increased in the ratio of 1.21 to 1.

Experiment (*h*). In order to form an idea of the amount of change with the state of the weather of the conductivity of a piece of our Carrara statuary marble, we made three comparisons on three different occasions of the relative conductivities of a slab of it (*C*) 1.08 centimeters thick, and a plate (*A*) of standard glass. Between the experiments, *C* was left in a room the windows of which were much of the time open. The results were as follows: —

Temperature of the warm side of the glass,	85°.5	84°.6	84°.8
Temperature of the cool side of the glass,	68°.1	67°.1	67°.4
Temperature of the warm side of the marble,	43°.0	42°.1	40°.3
Temperature of the cool side of the marble,	32°.0	31°.1	29°.4
Ratio of the conductivities of the marble and the glass,	1.84	1.84	1.83
Average conductivity of the slab *C*,		0.00509	

Another specimen of Carrara marble had a conductivity of 0.00501.

* We have not yet seen the paper by Mr. Lees mentioned in the March, 1898, number of the Beiblätter zu den Annalen der Physik und Chemie.

Before we state the results of our own observations upon other specimens, we will give for purposes of comparison some determinations of the thermal conductivities of marble made by other observers.

Material.	Observers.	Conductivity.
"Carrara Marble"	Stadler	0.0049
"White Italian Veined Marble"	Herschel, Lebour, and Dunn	0.0051
"Irish Green Marble"	" " "	0.0051
"Irish Fossil Marble"	" " "	0.0052
"White Sicilian Marble"	" " "	0.0054
White Marble	R. Weber	$0.0054(1.-0.000005t)$
White Marble	Lees	0.0071
"White Coarse-grained Marble"	Yamagawa	0.0073
"Sugar White Coarse-grained Marble"	Péclet	0.0077
"Fine-grained Gray Marble"	Péclet	0.0097

Taking a certain piece of "Pyrenees Marble" as a standard, Dr. Less found the conductivities of specimens of "Carrara Marble" and "Italian Marble" to be 0.769 and 0.763 respectively.

In determining the thermal conductivities of the specimens of marble mentioned below, the prism clamped between the hot and the cold box of our apparatus was made up of six slabs in series, a plate of standard glass 0.935 cm. thick between two thin plates of glass, and the slab to be tested between two thin slabs of marble. A ribbon thermal element and tinfoil wings were placed on each side of the standard glass, and on each side of the marble to be experimented on, so that there were four of these thermal elements in all. When the prism had sensibly reached its final state, the temperatures of the thermal junctions were determined and the ratio of the conductivities of the glass and the marble was assumed to be equal to the reciprocal of the ratio of the gradients in the two slabs. By introducing an extra plate or a sheet or two of blotting paper into the prism, the two gradients could be altered at pleasure but not their ratio. So far as we could see, it was immaterial in the case of these substances whether the marble base of the prism or the glass base was placed uppermost, but we generally placed the marble on top, so that the mean temperature of each specimen might be about 30° C. In stating the results of some of these determinations, we shall give the temperatures of the four thermal junctions in order, then the ratio of the conductivities of the marble to be tested and the standard glass, and finally the absolute conductivity of the marble on the assumption that that of the glass is 0.00277. We shall give the absolute conductivity of the marble to three significant figures, but it is evident that the last of these is not determined. All the specimens were artificially dried for some time in the hot air space over the boilers which furnish steam for heating the Jefferson Laboratory, and were then allowed to stand for some weeks at ordinary room temperatures so that their conditions might be normal. The artificial heating drove off the excess of moisture acquired by the marble while being cut under water at the mill.

Most of our stone was obtained from Messrs. Bowker and Torrey of Boston, who kindly collected for us representative specimens of such materials as are commonly used for decorative and monumental purposes. We have given to the slabs the names used by stone workers and have called them all "marbles," though one or two might more properly be called "limestones." The "Mexican Onyx" is really travertine. Our thanks are due to Prof. J. E. Wolff for help in identifying our specimens.

Fossiliferous Tennessee Marble.

(Red with numerous white fossils.)

Thickness in centimeters,	2.40
Temperatures of the faces of the glass plate,	82°.3 and 63°.2
Temperatures of the faces of the marble slab,	43°.3 and 24°.4
Ratio of the conductivities of the marble and the glass,	2.73
Absolute conductivity of the marble,	0.00756

American White Marble.

(Cream white.)

Thickness in centimeters,	2.68
Temperatures of the faces of the glass plate,	83°.6 and 64°.6
Temperatures of the faces of the marble slab,	45°.4 and 20°.3
Ratio of the conductivities of the marble and the glass,	2.15
Absolute conductivity of the marble,	0.00596

Vermont Statuary Marble.

(Snow white with coarse but uniform grain.)

Thickness in centimeters,	2.40
Temperatures of the faces of the glass plate,	82°.9 and 64°.2
Temperatures of the faces of the marble slab,	44°.7 and 21°.7
Ratio of the conductivities of the marble and the glass,	2.09
Absolute conductivity of the marble,	0.00578

Lisbon Marble.

(Light terra-cotta with darker veins.)

Thickness in centimeters,	2.30
Temperatures of the faces of the glass plate,	80°.9 and 60°.8
Temperatures of the faces of the marble slab,	39°.6 and 19°.6
Ratio of the conductivities of the marble and the glass,	2.47
Absolute conductivity of the marble	0.00685

St. Baume Marble.

(Yellow, red, and yellowish white brecciated.)

Thickness in centimeters,	2.36
Temperatures of the faces of the glass plate,	80°.9 and 61°.2
Temperatures of the faces of the marble slab,	40°.3 and 22°.1
Ratio of the conductivities of the marble and the glass,	2.75
Absolute conductivity of the marble,	0.00761

Rose Ivory Marble.

(From Djebel-er-Roos, Algiers. White with very slight pinkish tinge. Very fine in grain.)

Thickness in centimeters,	2.64
Temperatures of the faces of the glass plate,	80°.3 and 60°.2
Temperatures of the faces of the marble slab,	39°.8 and 19°.0
Ratio of the conductivities of the marble and the glass,	2.73
Absolute conductivity of the marble,	0.00756

Italian Egyptian Marble.

(Breccia. Slate colored with ochre-yellow and white veins.)

Thickness in centimeters,	2.55
Temperatures of the faces of the glass plate,	83°.0 and 63°.3
Temperatures of the faces of the marble slab,	43°.1 and 19°.2
Ratio of the conductivities of the marble and the glass,	2.25
Absolute conductivity of the marble,	0.00623

Mexican Onyx.

(Alabaster white, translucent.)

Thickness in centimetres,	2.29
Temperatures of the faces of the glass plate,	82°.9 and 63°.8
Temperatures of the faces of the onyx slab,	43°.1 and 19°.8
Ratio of the conductivities of the onyx and the glass,	2.01
Absolute conductivity of the oynx,	0.00556

Vermont Dove Colored Marble.

(Dove colored with light and dark striæ.)

Thickness in centimeters,	2.19
Temperatures of the faces of the glass plate,	80°.5 and 59°.3
Temperatures of the faces of the marble slab,	39°.1 and 18°.9
Ratio of the conductivities of the marble and the glass,	2.47
Absolute conductivity of the marble,	0.00684

Bardiglio Marble.

(From the Seravazza quarries. Cloudy white, with network of distinct dark lines.)

Thickness in centimeters,	2.44
Temperatures of the faces of the glass plate,	81°.8 and 61°.3
Temperatures of the faces of the marble plate,	41°.1 and 19°.3
Ratio of the conductivities of the marble and the glass,	2.45
Absolute conductivity of the marble,	0.00680

Sienna Marble.

(Yellowish white with blue veins.)

Thickness in centimeters,	2.48
Temperatures of the faces of the glass plate,	81°.5 and 60°.9
Temperatures of the faces of the marble plate,	40°.9 and 18°.6
Ratio of the conductivities of the marble and the glass,	2.44
Absolute conductivity of the marble,	0.00676

St. Anne Marble.

(Brown black with white patches.)

Thickness in centimeters,	2.34
Temperatures of the faces of the glass plate,	80°.9 and 60°.1
Temperatures of the faces of the marble plate,	38°.8 and 19°.7
Ratio of the conductivities of the marble and the glass,	2.73
Absolute conductivity of the marble,	0.00755

American Black Marble.

(Dark slate.)

Thickness in centimeters,	2.43
Temperatures of the faces of the glass plate,	81°.0 and 61°.1
Temperatures of the faces of the marble slab,	40°.1 and 19°.2
Ratio of the conductivities of the marble and the glass,	2.47
Absolute conductivity of the marble,	0.00685

Vermont Cloudy Marble.

(Cloudy white with darker patches.)

Thickness in centimeters,	2.55
Temperatures of the faces of the glass plate,	82°.3 and 62°.1
Temperatures of the faces of the marble slab,	41°.8 and 19°.4
Ratio of the conductivities of the marble and the glass,	2.46
Absolute conductivity of the marble,	0.00681

Knoxville Marble

(Pink with occasional dark serrated veins.)

Thickness in centimeters,	2.37
Temperatures of the faces of the glass plate,	81°.6 and 61°.0
Temperatures of the faces of the marble slab,	38°.9 and 20°.1
Ratio of the conductivities of the marble and the glass,	2.62
Absolute conductivity of the marble,	0.00757

Arranging the results in the order of the conductivities of the specimens, we get the subjoined table. We call attention to the two groups of fine-grained marbles, which have conductivities of about 0.0068 and 0.0076 respectively, at about 30° C.

Variety of Marble.	Conductivity.
"Carrara Statuary"	0.00501
" "	0.00509
"Mexican Onyx"	0.00556
"Vermont Statuary"	0.00578
"American White"	0.00596
"Egyptian"	0.00623
"Sienna"	0.00676
"Bardiglio"	0.00680
"Vermont Cloudy White"	0.00681
"Vermont Dove Colored"	0.00684
"Lisbon"	0.00685
"American Black"	0.00685
"Belgian"	0.00755
"African Rose Ivory"	0.00756
"Tennessee Fossiliferous"	0.00756
"Knoxville Pink"	0.00757
"St. Baume"	0.00761

We reserve for a second paper the results of observations made upon other materials.

Our acknowledgments are due to the American Academy of Arts and Sciences, which has made an appropriation from the Rumford Fund in aid of our work.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

THE CONTACT-POTENTIAL BETWEEN METALS AND FUSED SALTS, AND THE DISSOCIATION OF FUSED SALTS.

BY CLARENCE MCCHEYNE GORDON.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

THE CONTACT-POTENTIAL BETWEEN METALS AND FUSED SALTS, AND THE DISSOCIATION OF FUSED SALTS.

By Clarence McCheyne Gordon.

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Presented by Theodore W. Richards, October 12, 1898.

The potential difference between fused salts and metals immersed in them is a quantity of great importance because of its relation to the theory of the origin of contact-potentials, on account of the light it throws upon the degree of dissociation of salts in their fused state, and in view of its bearing upon the electrolytic separation of the metals. Notwithstanding these important relations, the subject has received practically no attention at the hands of scientific investigators. In a few cases cells containing fused salts as the electrolyte have been measured, but always with some other end in view than the study of the single potential difference between metal and salt.*

The practical difficulties in the way of carrying out an exhaustive investigation of this subject are many. Among the more important of these are the fact that many salts decompose below or slightly above their melting point, the disturbing effect of side reactions which at ordinary temperatures would be so slow as to cause little or no inconvenience, and the impossibility of using glass vessels at temperatures as high as the melting points of most inorganic salts. Such difficulties as these have prevented me from extending the investigation rapidly, but the results

* Lash Miller (Zeit. für phys. Chemie, X. 459, 1892) used fused salts in experiments to prove that there was no change in the contact-potential as the metal changed from liquid to solid state.

Poincaré (Ann. chim. et phys., [6.], XXI. 289, 1890) measured reversible cells containing melted zinc and tin salts with the heat of reaction as the end in view. He investigated also some polarization phenomena with silver electrodes.

from the cells so far measured seem of such value that I give them in this preliminary paper, hoping to extend the investigation to other salts and metals in the near future.

For dilute water solutions the variation of the potential between a metal and a solution of a salt, whose kation is the metal of the electrode, is given by the well known Nernst formula,*

$$E_1 - E_2 = \frac{RT}{n} \log_e \frac{C_2}{C_1},$$

where E_1, E_2, are the respective potentials for the concentrations C_1, C_2; R, the gas constant; T, the absolute temperature; and n, the valency of the metal. In the derivation of this formula the gas law, $pv = RT$, is applied to the dissolved salt, and complete dissociation is assumed. In case the dissociation is not complete, C_1, C_2, denote the concentration of the dissociated part.

For fused salts, in case the solutions are sufficiently dilute, we might expect the same or an analogous formula to hold. Any experimental evidence, however, for the applicability of the gas law to fused salt solutions, or as to the amount of dissociation, has been lacking.

Accordingly, the first question to be determined was whether or not, for any measureable range of concentrations, the potential difference would vary according to the Nernst formula.

So far all my observations have been upon silver electrodes immersed in fused mixtures containing varying amounts of silver salts. Most of the cells measured were simple silver nitrate concentration cells of the type,

$$\text{Ag} \left| \begin{array}{c} x_1 AgNO_3 \\ \text{in} \\ y_1 KNO_3 + y_1 NaNO_3 \end{array} \right| \begin{array}{c} x_2 AgNO_3 \\ \text{in} \\ y_2 KNO_3 + y_2 NaNO_3 \end{array} \right| \text{Ag.}$$

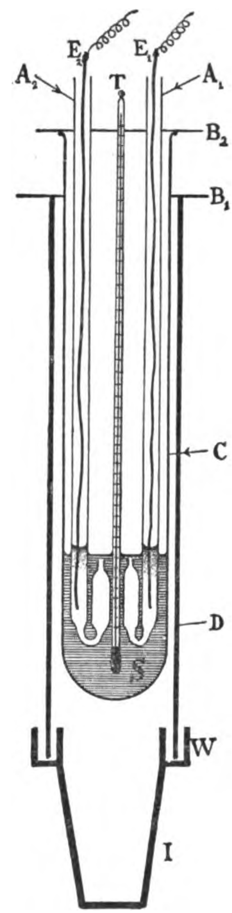
The mixture of potassium and sodium nitrates, rather than either alone, was used as solvent in order to obtain a lower melting point.

Experimental.

General. — In a few preliminary measurements I tried keeping the temperature constant with an air bath, but was unable to attain much constancy, and therefore substituted a vapor bath. The practical arrangement of the cell in its constant temperature vapor bath is shown in the opposite figure.

* See Nernst, Zeit. für phys. Chemie, IV. 129, 1889.

The jacket D, containing the vapor, is a thin-walled glass cylinder about 5 cm. in diameter, joined below by means of a Wood's metal or mercury joint, W, to a cast-iron cup, I, on which the heating flame plays. This vapor bath arrangement is such as is in common use for V. Meyer vapor density determinations at moderately high temperatures, except that in the present case the jacket tube was shortened. Inside of this vapor jacket is the large test tube C, extending about 25 cm. below the top of the outside jacket. So much of the upper opening of the cylinder D as the tube C does not fill is closed with the asbestos sheet B_1. This covering is of course not air tight, but makes it possible for the vapor to ascend near the top without any rapid escape into the room. In the tube C is the cell to be measured. It consists of the silver electrodes E_1, E_2, in the tubes A_1, A_2, which contain the two differently concentrated solutions of silver nitrate, and the connecting solution S. The capillary ends of the tubes A_1, A_2, were lowered beneath the surface of the connecting liquid only long enough for the measurements to be taken. In order to prevent air circulation, the top of the tube C was covered with an asbestos sheet having holes for the tubes A and the thermometer T.



One Fourth Natural Size.

The heat was supplied by a three-tube Bunsen burner, fed from a gas supply containing a good pressure regulator. By reason of this regulator, when the gas was once adjusted, no care was required to keep the height of the vapor constant, except as the amount of boiling substance made slow escape into the room. The top of the condensing vapor column could be plainly seen, and was kept constant about 18 cm. above the lower end of the tube C. With this arrangement any difference in temperature between the upper and lower part of the liquid S was unnoticeable.

Temperature. — The cells were measured at two temperatures, that of boiling diphenylamine, and of boiling chinoline. The former was taken

from the laboratory stock, and the latter was made for me by Mr. J. B. Churchill, whom I wish to thank for providing me with a very considerable amount. Since the temperatures were read on a mercury thermometer in the cell itself, no attempt was made to attain absolute purity in the boiling substances.

The most of the cells measured were liable to variations due to other causes than change of temperature of about 0.001 volt. This was the accuracy of measurement aimed at. As it was found to require a change of about 5° in temperature to cause a change of 0.001 volt, the temperatures were read on a thermometer graduated to degrees, and considered constant as long as they did not vary more than 1°.

In order to standardize the thermometer used, it was tested with pure naphthalene. According to Crafts,* naphthalene boils under 756 mm. pressure at 217°.9. The thermometer used for these experiments registered 218° as the boiling point under the same pressure. The actual readings of the thermometer were therefore taken as correct.†

Change in Concentration. — In order to render the danger of change in concentration in the neighborhood of the electrodes as small as possible, the tubes *A* were given the shape shown in the figure. In the preliminary measurements, however, there was still trouble on this account. This was due to the fact that the salts were put into the tubes in the unmelted state. Air was unavoidably retained when the salt was fused, which must necessarily be blown out after the tubes were lowered under the level of the connecting solution, and the latter was thus brought into the tubes. As the potentials were measured by means of a capillary electrometer, even when the air filled the whole cross-section of the capillary, the measurement could be made; the value was, however, always different from the true one. In order to avoid this trouble due to air bubbles, the filling of the cell tubes with the pulverized salts was

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* Amer. Chem. Journ., V. 307, 1883–84.

† Graebe (Annalen [Liebig's], CCXXXVIII. 362) finds the boiling point of diphenylamine to be 302°. The earlier determinations of Hofmann, Girard and Wilson, and Kreis, etc., are evidently incorrect, as Graebe standardized his thermometers with benzophenone, according to the figures of Crafts. Whether the difference between Graebe's 302° and the reading 298° of my thermometer in the cell surrounded by the diphenylamine was due to impurities in the latter, to a change in the value of the marked degree between 218° (the point found to be correct), or to the fact that the thermometer in the cell was at a little lower temperature than the surrounding vapor, I have not attempted to determine, since a change of even 4° in temperature would cause a change in voltage in the cells measured of less than 0.001 volt.

abandoned. Instead, the salts were first melted in a test tube, and when they were about the temperature of the constant temperature bath, the cell tubes were filled by immersion, and then transferred to the tube *C*. After this method of filling was adopted, no change of concentration was noticed.

The Connecting Solution. — The solution *S*, which served to connect the two differently concentrated silver nitrate solutions, consisted of equal parts potassium and sodium nitrates, with some silver nitrate. For the cells of small concentration it contained the same proportion of silver nitrate as the less concentrated of the solutions in the tubes *A*. Since it was found experimentally that the amount of silver nitrate in this connecting solution had no effect on the value of the potential, for the concentrated cells it was not accurately determined, but was about 10% $AgNO_3$.

Preparation of Solutions. — The potassium and sodium nitrates used were purified by recrystallization. Crystallized argentic nitrate is easily obtained in a condition pure enough for the end in view.

The concentrations of the silver nitrate ranged from 0.001 of total weight to pure silver nitrate. 50% and 10% solutions were weighed out and fused in rather large quantities, and the other solutions made by dilution of these.

The Molecular Concentrations. — While the solutions were naturally made up by weight, it is the molecular volume concentrations, which are to be used in the calculation. In order to obtain these it was necessary to measure the specific gravities of the several mixtures. This was done at the temperature of the chinoline bath, 236°. Since the expansion coefficients for these salts, as found by Poincaré,* are small, we can for our purpose consider the concentrations at 298° to be the same. In order to obtain the specific gravities, tubes of about 0.5 cm. internal diameter were narrowed still more a few centimeters from the lower closed end, and filled to a marked point on the narrow portion of the tubes while in the chinoline bath. After cooling, the tubes were broken off at the marked point, weighed, and the volumes determined by weighing with water, applying the correction for expansion of the glass. The specific gravities measured, and the molecular concentration calculated therefrom are given in the following table.

* *Loc. cit.*

TABLE I.

Per Cent by weight $AgNO_3$.	Specific Gravity.	g-mol. $AgNO_3$ in liter.
0.1	1.84	0.0108
1.	. . .	0.11 (estimated).
10.	2.02	1.16
50.	2.61	7.68
100.	3.82	22.5

The Electrodes. — Pure silver wires served as electrodes. It was found experimentally that no special care need be taken as to the character of their surface. In view of the irregularities shown by solid metal electrodes in water solutions, this independence of the character of the surface and previous treatment of the electrodes is quite remarkable. As a matter of precaution the wires were scraped with a clean knife, washed, and dried with filter paper before using. Tests were made on several electrodes so treated by putting them into the same solution. They did not give a difference of potential of more than 0.0001 volt.

Measurement of the Potential Difference. — Above the cell tubes the silver wires were soldered to copper ones, and the potential difference measured by the Poggendorf method, using a Leclanché cell, an Ostwald potential box, and a capillary electrometer. A previously standardized one-volt Helmholtz cell was taken as the standard of electromotive force. The electrometer was read with a microscope, and would readily show a difference of 0.0004 volt.

No noticeable error could result from the possible difference in temperature of the two copper-silver junctions.

The Conductivity of Glass. — Although the temperatures used for these nitrate cells were far below the softening point of glass, its conductivity is, even at 200°, very considerable, being of about the same order of magnitude as a $\frac{1}{100000}$ normal KCl solution. Measurements could indeed be made with the capillary electrometer without having any liquid connection between the two $AgNO_3$ solutions. The potentials so measured (with the two cell tubes closed at the lower end) differed from the true ones generally by about 0.02 volt. The conductivity, however, of the fused salts is so great as to preclude any disturbance from conductivity of the glass when the liquid connection is made.

Results of the Experiments.

The potentials of four such silver nitrate cells are given in the following table. The calculated values are obtained by substitution of the absolute temperatures and the molecular concentrations, as given in Table I., in the Nernst formula,

$$E_1 - E_2 = RT \log_e \frac{C_2}{C_1}.$$

TABLE II.

Silver Nitrate Cells.

No.	Per Cent $AgNO_3$.		Chinoline bath.			Diphenylamine bath.		
	Sol. 1.	Sol. 2.	T.	E. M. F.		T.	E. M. F.	
			°C.	Calc.	Observed.	°C.	Calc.	Observed.
1	1.	0.1	232	0.101	0.100	298	0.114	0.110
2	10.	1.	"	0.102	0.100	"	0.115	0.112
3	50.	10.	236	0.082	0.071	"	0.093	0.080
4	100.	50.	"	0.045	0.039	"	0.051	0.045

In general I can say that the measurements were all repeated several times, and only in a few cases were there single measurements varying as much as 0.001 of a volt from the mean as here given. The behavior of the several cells with regard to their constancy requires individual mention.

No. 1, at 298°, decreased rapidly in potential after first setting up, but when the 0.1% solution was replaced by that of the outside connecting solution (of same concentration), the value 0.110 volt was always obtained. Five minutes later it had always decreased, in one case to as low as 0.100 volt. This rapid decrease in value may account for the fact that the observed value is 0.004 volt less than the calculated. Had the measurement been taken *immediately* after the fresh solution came in contact with the electrode, the observed value might have been larger. This value was obtained repeatedly, however, the measurement being taken about one minute after the introduction of the fresh solution into the cell tube.

In the chinoline bath cell No. 1 remained constant for from ten to fifteen minutes, and then decreased. It could be brought back to the

original value by replacing the weaker of the two solutions with that of the connecting solution (of the same concentration).

Cell No. 2, at 298°, remained constant for at least twenty minutes after the 1% solution in the neighborhood of the electrode was replenished. Of four cells measured, one decreased in value, and three increased, on standing.

This cell in the chinoline bath remained constant for several hours.

Cells 3 and 4 were extremely constant for several hours at a time, and the same solutions in the same tubes could be heated up several days in succession, and would always give the same value.

The inconstancy of the cells containing very dilute solutions would seem to indicate that in these there is a slow reaction going on between the solution and the electrode. The fact that the replenishing of the solution with that which had not been in contact with the electrode always brought the cell back to the same value, shows that the reaction did not take place throughout the solution as a whole, but only in the neighborhood of the electrode. The more rapid variation at the higher temperature shows that, whatever the reaction may be, its speed increases with the temperature. Obviously a slow dissolving of the silver electrode in the fused salt would account for the observations, the weak solutions being much more affected by this possible irregularity than the strong ones; but this hypothesis is not advanced as a certainty.

The observed values for the cells No. 1 and No. 2 agree remarkably well with the calculated. We must conclude that the osmotic theory of electromotive forces can be extended to the case of fused salts, and that even in a 10% solution the silver nitrate is almost wholly dissociated.

In considering the observed potential to be the difference between the two electrode potentials, we assume that the potential difference between the two differently concentrated solutions is so small as to be negligible. While the good agreement between the values found and calculated is the strongest argument in favor of this supposition, it is to be inferred also from what we know of aqueous solutions. Such potential differences depend on the difference in transference numbers of the two ions. Nernst and Loeb,* and more especially W. Bein,† have shown that the transference numbers all tend toward the value 0.5 as the temperature increases. For $AgNO_3$ especially, they are never far from 0.5, and approach very near it at the highest temperature measured. W. Bein

* Zeit. für phys. Chemie, II. 962, 1888.
† Wied. Ann., XLVI. 69, 1892.

found for the transference number of NO_3 in $AgNO_3$, 0.470 at 20°, and 0.490 at 90°.

Dissociation. — In view of the agreement with the formula in case of dilute solutions, the consideration of the cells containing the more concentrated solution becomes of greatest interest. It seems probable that the deviations from the calculated values are here due entirely to incomplete dissociation. We thus have a means of calculating the degree of dissociation for the 50% $AgNO_3$ solution, and for the pure salt. The results of this reckoning are given in Table III.

TABLE III.

DISSOCIATION OF SILVER NITRATE.

Temperature 236°. Dissociation 0.1% sol. assumed complete.

Per Cent $AgNO_3$.	$\log \frac{C_2}{C_1}$		Degree of Dissociation.
	By Measurement.	Calc. from E. M. F.	
50.	2.8508	2.6912	0.69
100.	3.3172	3.0784	0.58

This is, so far as I know, the first determination of the degree of dissociation of a fused salt. To say that pure fused silver nitrate is 58% dissociated seems at first thought somewhat incredible; especially when we think of the almost infinitesimal dissociation of water and other liquids at ordinary temperatures. These are not the only measurements, however, that go to show that the degree of dissociation is large. Their large conductivities, and the small range of the same when different salts are considered, are in favor of it. The careful measurements of Poincaré * on the conductivity of fused salt mixtures show a behavior very different from that of electrolytic solutions at ordinary temperatures. In the latter case the conductivity is generally greatly changed, or first made possible, by the mixing, while for fused salts the conductivity is almost an additive property of the separate salts. The large amount of dissociation gives at least a qualitative explanation of this apparently anomalous behavior.

* *Loc. cit.*

Before the above cells were measured, cells of the following types were studied: —

$$Zn - ZnCl_2 - AgCl \text{ in } ZnCl_2 - Ag,$$
$$Zn - ZnBr_2 - AgBr \text{ in } ZnBr_2 - Ag.$$

The observed values corresponded roughly with those calculated, but the readings were not constant enough to be worthy of detailed mention. In the hope of securing greater constancy silver was substituted for zinc, and two different strengths of argentic halide dissolved in zincic halide were used around the electrodes, as in the experiments with the nitrates. These also were not constant, and some interesting phenomena concerning their inconstancy are worthy of further investigation. After the partial failure of these two attempts, the nitrates were resorted to with the satisfactory and interesting results described above.

These measurements were carried on in the Laboratory of Physical Chemistry in Boylston Hall, Harvard University. I wish to thank Professor Theodore W. Richards for his kindly interest and aid in the investigation, and especially for his many helpful suggestions when experimental difficulties were encountered.

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ON FLUCTUATIONS IN THE COMPOSITION OF NATURAL GAS.

By Francis C. Phillips.

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ON FLUCTUATIONS IN THE COMPOSITION OF NATURAL GAS.*

By Francis C. Phillips.

Presented by the C. M. Warren Committee, October 12, 1898.

Received October 12, 1898.

At the mills and factories of the Pittsburgh region the opinion is often expressed by men in charge of steam boilers where natural gas is the fuel used, that the gas fluctuates in its heating power, and that at certain times more gas must be used than at others to accomplish the same work. Changes of pressure in the mains, owing to varying demands upon the supply, requiring that the valve controlling the admission of gas to a boiler fire should occasionally be opened more widely, might readily lead to the supposition that the gas at such times possesses less heating power and consequently a different composition.

No data as regards results in practice have been obtainable, but in analyses of gas from various wells in the Pittsburgh region reasons have been found for supposing that slight fluctuations actually occur in its composition. With a view to a more complete study of the question, the experiments described in this paper were carried out.

As regards the character and number of its chief constituents natural gas differs widely from coal gas, and from gas manufactured at high temperatures in the various forms of producers. While in artificial gas unsaturated compounds are present in great variety, natural gas is composed mainly of hydrocarbons of the paraffin series, associated with very small quantities of nitrogen, carbon dioxide, and water vapor. The olefines, represented mainly by ethylene, are found sometimes in extremely minute proportion, so minute in fact that quantitative determinations are a matter of difficulty, although they are qualitatively recognizable when large volumes of gas are employed. Traces of organic sulphur com-

* Acknowledgment is here made of aid received from the C. M. Warren Fund of the American Academy of Arts and Sciences, in conducting the experiments described in this paper.

pounds are also present. Free hydrogen, carbon monoxide, hydrogen sulphide, and oxygen do not occur.

It is a difficult matter to single out any of the constituents of natural gas as specially suited for a series of determinations having for their purpose to ascertain whether fluctuations actually occur in its composition. One of its constituents — nitrogen — seems to be less prone than the others to enter into chemical changes locally in the rocks, and therefore less likely to undergo diminution in the original gas as it is stored in the interstices of the sandstones and limestones of the Devonian formation. It might be proper to begin such a study with nitrogen.

Under the term nitrogen is here understood the incombustible residue obtained when natural gas is burnt in such manner as to prevent the admixture of air or oxygen with the products. That the element nitrogen is actually contained in natural gas has been frequently shown by passing the gas over heated magnesium. The magnesium, on being afterwards moistened, yielded ammonia, recognizable by its odor and reactions, and indicating the presence of nitrogen in the original gas.

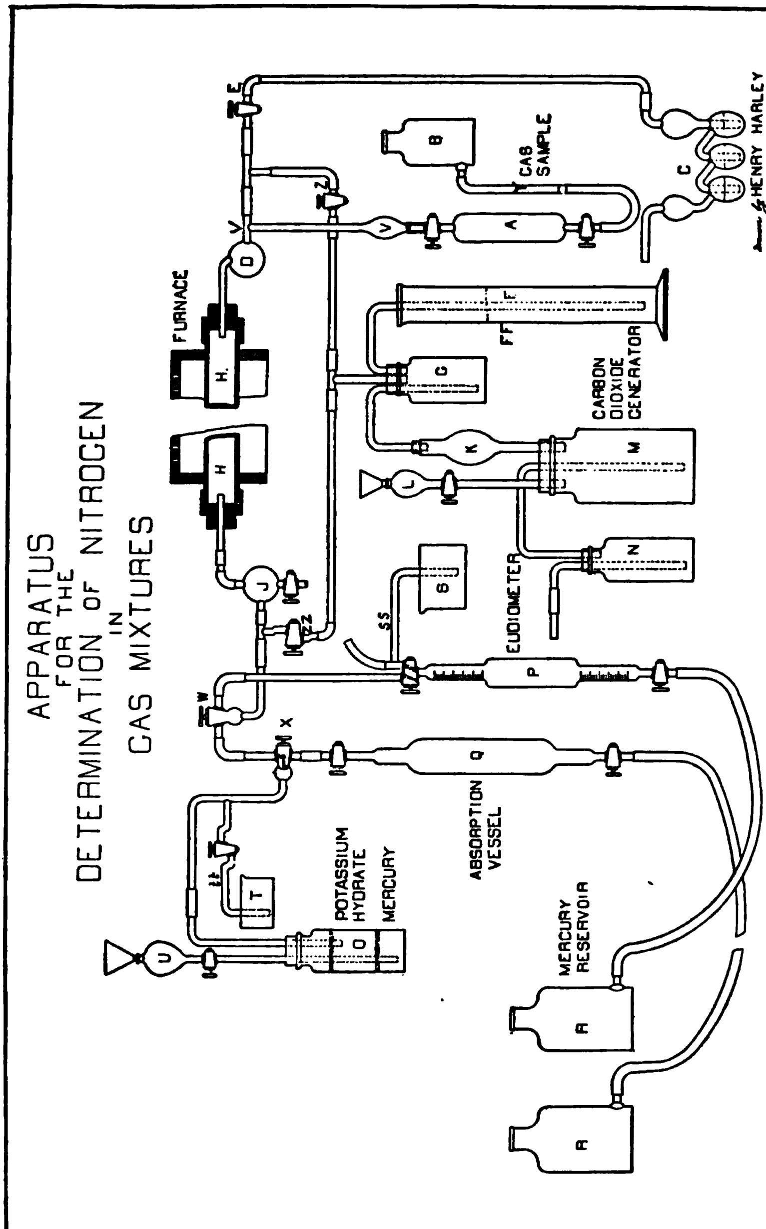
The method employed for the determination of nitrogen consisted in burning a measured volume of natural gas by passing it over heated copper oxide. The resulting steam was condensed and the carbon dioxide absorbed by potassium hydroxide solution, leaving the residual nitrogen to be measured over mercury. This adaptation of the Dumas method has been proposed by Stöckmann for the determination of nitrogen in coal gas.* Arth has described an apparatus for a similar purpose, the gas measurements being made over water.†

Description of the Process.

The gas sample was collected in a glass cylinder of from 150 to 400 c. c. capacity, and having stopcocks at both ends. In the drawing of the apparatus *A* represents the gas sample vessel with its stopcocks and capillary endings. Vessels of 150 c. c. proved sufficiently large for the determination, although in the later work, where it was desirable to collect a larger volume of the residual incombustible gas, vessels of 350 to 400 c. c. were used. These vessels were calibrated by weighing the mercury required to fill them. They were filled with gas under slight excess of pressure (about two ounces). With a view to determining by calculation the volume at 0° and 760 mm. pressure of the

* Zeitschrift für Analyt. Chemie, 1875, p. 46.

† Bull. Soc. Chim., 1897, p. 80.


APPARATUS
FOR THE
DETERMINATION OF NITROGEN
IN
GAS MIXTURES
FURNACE
GAS SAMPLE
CARBON
DIOXIDE
GENERATOR
EUDIOMETER
ABSORPTION
VESSEL
POTASSIUM
HYDRATE
MERCURY
MERCURY
RESERVOIR
HENRY HARLEY

contained gas, the vessels after return to the laboratory were placed vertically in a large box having glass sides, and in such a position that the lower stopcock projected through a thick rubber disk set in the bottom of the box and having an opening just large enough for the stopcock to pass through it. The temperature in the box was indicated by a thermometer, which could at all times be read through the glass panes. When this temperature had remained constant for at least one hour, the lower stopcock was opened for an instant allowing the surplus gas to escape. A glass tube, connected by rubber joint with the lower end of the stopcock, and just touching, but not dipping under the surface of water, afforded a simple and safe means of preventing the possibility of the entrance of air during the equalizing of the pressure. After opening and shutting the stopcock the pressure of the contained gas was assumed to be that of the air outside, as indicated by the barometer. A drop of water was always introduced into the sample vessel before it was filled, so that the gas could be regarded as saturated with moisture when used for analysis.

The gas vessel was connected with a mercury bottle *B*, the capillary tubes at the ends of the cylinder having been filled with mercury before the connections were made. By raising the bottle *B* and opening the stopcocks the gas was slowly driven over from *A* through the glass tube *VVD* into the porcelain combustion tube *HH*, which contained a layer of heated copper oxide forty centimeters long. The porcelain tube was heated in a combustion furnace (partly shown in the sketch). The products of combustion of the gas passed by way of the glass bulb *J* and the stopcocks *W* and *X* to the absorpion vessel *Q*, in which the carbon dioxide was absorbed by solution of potassium hydroxide. This solution was delivered over when needed from the bottle *O*, by pouring mercury into the tap funnel *U*. The residual gas, after the absorption of the carbon dioxide in *Q* was then caused to return by the same route to the cylinder *A*, by adjusting the levels of the mercury reservoirs *B* and *R*. A third passage of the gas over from *A* to *Q* rendered it certain that all hydrocarbons were completely burnt. The bulb *J*, and the combination of bulb with three way tube *DVV* served to condense and hold as water any steam due to burning of hydrogen of the gas in the combustion tube, and prevent its return into the heated porcelain tube. These bulbs proved very necessary to prevent breakage. The stopcock on the bulb *J* served to discharge this condensed water. As it was necessary to rinse the porcelain tube and its glass connections after the passage of the gas from *A* to *Q*, or from *Q* to *A*, this was accomplished

by means of a slow stream of carbon dioxide generated by the action of concentrated hydrochloric acid upon calcite in the large jar *M*. This jar contained about five pounds of calcite at starting. The escaping carbon dioxide passed through fragments of calcite in the tube *K*, and through water in the bottle *G*. From this wash-bottle the gas stream could be deflected to the right hand end of the combustion tube, as seen in the sketch, entering this tube by the stopcock *Z* in rinsing gas into the absorption vessel *Q*, or to the left, by way of the stopcock *ZZ* in rinsing gas back into the vessel *A*. In this manner the rinsing out of the products of combustion into either *A* or *Q* could be made very complete. The tube *F*, descending into water in the open cylinder *FF*, served as a safety valve to permit the escape of surplus carbon dioxide from the generator, and thus any unsafe pressure in the apparatus was avoided. The carbon dioxide could, therefore, be generated freely and utilized only in so far as it was needed. It is to be observed that the long glass tube connecting the stopcocks *Z* and *ZZ* lies in the same horizontal plane with the combustion tube *HH*, although in the sketch it appears lower, in order that the arrangement of parts may be rendered clear. The carbon dioxide having been absorbed in *Q*, the residual gas was ready for measurement which was accomplished in the eudiometer *P* over mercury. This eudiometer was of 100 c.c. capacity, being made very short as shown (about forty centimeters long). It was graduated only in its uppermost and lowermost portions. This is a convenient form of eudiometer where mercury is used, as it avoids the great pressure of a high mercury column, and consequent danger of leakage through the stopcocks, so common where a high column of mercury is used. It is easily seen that by lowering sufficiently the bottle *R* any volume of gas, up to 100 c.c. may be readily measured. The combustion furnace stood somewhat higher than the upper end of the eudiometer. It was surrounded closely by sheet iron sides, which served to carry upward the waste heat. No difficulty was experienced in maintaining a constant temperature about the eudiometer, as indicated by a thermometer reading to 0.05°, placed in contact with its sides. By reason of the strong upward draught produced by a sheet iron box placed around and in close contact with the sides and ends of an ordinary combustion furnace, much may be done towards diminishing the discomfort of the experimenter, while the temperature of the interior of the furnace is increased, and the ends of the tube are more readily kept cool. The tube *tt*, dipping into water in the beaker *T*, serves to discharge the absorption vessel after a determination. In a similar manner the eudiometer may be

discharged of its contents by the tube *ss* dipping into the beaker *S*. The tube *E* serves to discharge carbon dioxide through a Liebig's bulb having a water seal, when the apparatus is being cleared of air preparatory to a determination. The various forms of stopcocks used are sufficiently indicated by the sketch. The time required for a nitrogen determination was from one and a half to two hours when 150 c. c. of gas were used. Two or three days were sometimes occupied in expelling the last traces of air from the apparatus by the slowly passing carbon dioxide stream preparatory to a series of determinations.

The potassium hydroxide solution was of 1.258 specific gravity, as recommended by Kreusler,* and the measurement of the nitrogen was always made with a little of the fresh solution resting upon the mercury in the eudiometer. The mercury reservoirs, *R*, *R*, were attached to supports sliding vertically in wooden frames (not shown), and the reservoir connected with the eudiometer could be adjusted by screw movement so as to bring the mercury in the reservoir and that in the eudiometer to the same level. Readings were made by an accurate cathetometer. The pressures of mercury columns were all calculated at 0°.

A very high temperature was found to be necessary for the complete combustion of the hydrocarbons of natural gas, under the conditions of the method, the excess of carbon dioxide produced causing retardation. No difficulty was experienced, however, as repeated tests demonstrated that the residual gas did not contain carbon monoxide or free hydrogen. Moreover, it was repeatedly found that on passage of the residual gas for a fourth and fifth time through the copper oxide, and absorption of the carbon dioxide, no further reduction of volume was produced. The constantly increasing amount of reduced copper in the porcelain tube, as combustion goes on, serves to prevent the escape undecomposed of any oxides of nitrogen, should such compounds tend to form during the process.

In order to procure pure carbon dioxide for the Dumas method of nitrogen determination in organic bodies, it has been recommended that the marble to be used be first pulverized and then boiled in water before its carbon dioxide is liberated by the action of an acid. Bernthsen † frees the pores of the marble from air by exhaustion with an air pump. In experiments tried with a view to producing pure carbon dioxide these methods have not always proved satisfactory. The carbon dioxide stored

* Zeitschrift für Analyt. Chemie, 1885, p. 445.

† Zeitschrift für Analyt. Chemie, 1882, p. 63.

in liquid form in steel cylinders was tried. It was found, however, that the gas leaves a considerable volume of unabsorbed residue when treated with the solution of a caustic alkali. Sodium carbonate was tried instead of marble. A hot saturated solution of the salt was allowed to crystallize in the generator and the mother liquid poured off. The carbon dioxide produced by action of an acid is purer than that from marble, but the evolution of the gas is tumultuous and uncontrollable. Experiments were tried with marble from various localities, but with little success. A marble from Tate, Georgia, was found to yield very pure carbon dioxide after it had been coarsely pulverised and well boiled in water. Another sample of apparently the same rock, from the same locality, yielded after similar treatment a small residue of gas unabsorbed by potassium hydroxide solution. A calcite from Lampasas, Texas, in translucent cleavable crystals, was found to yield satisfactory results. The mineral was crushed coarsely, boiled for six hours in water, and then transferred with a portion of the boiled water to the generator. The carbon dioxide evolved proved to be very pure. Experience has shown that no reliance can be placed upon marble or calcite as a source of carbon dioxide because a specimen of apparently the same mineral known to come from the same locality has proved satisfactory. Every batch must be separately tested as regards the purity of the carbon dioxide which it evolves.

To overcome the danger of the action of strong alkali upon stopcocks in such work, it was necessary to use an unsaponifiable lubricant. After numerous trials it was found that a mixture, consisting of 70 parts melted rubber and 30 parts unbleached beeswax, softened with a little vaseline, served the purpose quite well, protecting the stopcocks completely. More than 150 determinations have been made in the same eudiometer without accident to stopcocks.

Some difficulty was experienced in expelling air from the copper oxide when the apparatus was being prepared for work. In beginning a series of determinations several days were often required for the purpose. The porcelain tube was strongly heated, while a slow stream of carbon dioxide was maintained, and the copper oxide was not considered to be in proper condition for use until the escaping carbon dioxide was found to be absorbed without residue by potassium hydroxide solution. About 300 c. c. of the escaping gas were used for the trial. When the copper oxide was freed from air, determinations of nitrogen in natural gas could follow each other until from experience it was shown to be necessary to reoxidize the partially reduced copper oxide. About ten determinations

could be made before this reoxidation was needed. Regeneration of the copper oxide was effected by drawing air through the apparatus while hot. It was found that the copper oxide when once impregnated with carbon dioxide *while strongly heated* could be reoxidized by an air current with very little tendency to occlusion of air. After the passage of air for a few hours, a stream of carbon dioxide readily expelled the remaining air and the apparatus was again ready for further determinations. But if the copper oxide was allowed to cool in contact with air, much time was lost in removing the air by the current of carbon dioxide, even when strong heat was applied during the process. It appears that little or no occlusion of air takes place when the copper oxide is first impregnated with carbon dioxide, while the same substance exposed to air in the cold occludes the air and holds it with much persistence.

Selection of Samples of Gas.

Many of the wells are drilled through several different gas producing sand rocks, separated by deep layers of impervious shales and other strata. The gas from these different sands mingles, and the product flowing from a single well is often a mixture of gas from formations many hundred feet apart in the vertical scale. It was attempted as far as possible in the present work to secure samples from wells yielding gas from a single sand rock. It was desirable that the samples be taken as far as possible from wells situated at no great distance from the laboratory, in order that as short a time as possible should elapse between the collection of the sample and the commencement of the analysis.

Results of Determinations of Nitrogen.

1. Gas well at Shields, 14 miles west of Pittsburgh. This well was drilled in 1892, and yields gas exclusively from the Fourth Sand, which was reached in drilling at a depth of 1,760 feet.

Date of Collection of Samples.		Percentage of Nitrogen found.
August 5, 1896	(1)	1.25
	(2)	1.26
February 5, 1897	(1)	2.70
	(2)	2.67
	(3)	2.68
April 6, 1897	(1)	1.79
	(2)	1.80
April 20, 1897	(1)	1.85
	(2)	1.85
June 1, 1898	(1)	1.10
	(2)	1.10

2. Well on the Anderson farm at Sewickley, 12½ miles west from Pittsburgh. This well was drilled in 1894, and yields gas exclusively from the Third Sand, which was found at a depth of 1,850 feet.

Date of Collection of Samples.	Percentage of Nitrogen found.	
July 7, 1896	(1)	2.48
	(2)	2.50
August 14, 1896	(1)	1.72
	(2)	1.71
March 22, 1897	(1)	2.11
	(2)	2.10

3. Well on the Müller farm at Glenfield, Pa., 9½ miles west from Pittsburgh. Drilled in 1887. The gas is produced mainly from the Fourth Sand, although a little gas finds access to this well from the upper sands. The Fourth Sand was reached in this well at a depth of 1,800 feet.

Date of Collection of Samples.	Percentage of Nitrogen found.	
July 27, 1896	(1)	1.52
August 17, 1896	(1)	1.69
	(2)	1.69
April 2, 1897	(1)	3.24
	(2)	3.25
April 16, 1897	(1)	3.23
	(2)	3.21
April 28, 1897	(1)	3.23
	(2)	3.20
May 4, 1897	(1)	3.20
	(2)	3.22
April 8, 1898	(1)	2.10
	(2)	2.10
April 21, 1898	(1)	2.12
	(2)	Lost.
June 9, 1898	(1)	1.27
	(2)	1.30
June 13, 1898	(1)	1.23
	(2)	1.22

4. Well on the Bayley farm, Neville Island in the Ohio River, 6½ miles west from Pittsburgh. The well was drilled in 1892. Gas is

derived from the "thirty-foot" sand alone, which rock was found at a depth of 1,510 feet.

Date of Collection of Samples.	Percentage of Nitrogen found.
August 1, 1896	(1) 1.46
	(2) 1.48
April 12, 1897	(1) 2.10
	(2) 2.11
April 24, 1897	(1) 2.10
	(2) 2.09
May 27, 1898	(1) 1.49
	(2) 1.48

5. Well on the Hamilton farm, Neville Island in the Ohio River, 7 miles west from Pittsburgh. The gas was derived from the Third Sand, which was reached at a depth of 1,580 feet, although there was a slight flow of gas from the Fifth Sand, which was reached at 1,729 feet. The well was drilled during the spring of 1898. The first sample of gas below mentioned was taken about 24 hours after the gas had been turned into the mains.

Date of Collection of Samples.	Percentage of Nitrogen found.
May 16, 1898	(1) 1.78
	(2) 1.76
May 19, 1898	(1) 1.74
	(2) 1.74

6. Well on the King farm at Murraysville, 18 miles east from Pittsburgh. The gas is derived from the Murraysville Sand at a depth of 1,336 feet. The well was drilled in 1887. Analyses of samples taken on a single date are presented, but this gas is of interest in the present connection, as the Murraysville gas field was among the earliest explored. The pressure in the rock has fallen from about 500 pounds to so low a point that at certain seasons of the year, when the demand is greatest, the gas is regularly pumped from the wells into the mains. Pumping was not in progress when the samples were taken.

Determinations of nitrogen in samples collected June 6, 1898, gave: —

(1) 1.29.
(2) 1.28.

7. Another well on the same farm at Murraysville yields gas exclusively from a sand about 100 feet deeper. Gas collected on the same

date from this well was found to contain the following percentages of nitrogen: —

(1) 1.38.
(2) 1.40.

8. Well on the Souder farm, 12 miles east of Buffalo. This well was drilled in 1892, and yields gas from the Trenton Limestone exclusively. Mr. E. Coste, Engineer for the Provincial Natural Gas Company of Buffalo, is authority for the statement that the drill passed through the base of the Trenton Limestone 30 feet below the point at which the gas was obtained. Hence the horizon from which this gas comes is extremely low in the geological scale as compared with the productive formations of the Pennsylvania gas fields.

Samples were collected at this well on September 3, 1896. The results of the analyses are as follows: —

(1) 4.57.
(2) 4.55.

9. Well on the Reinhart farm, near Sherkston, 10 miles east from Buffalo. In this well the gas is derived solely from the Clinton Limestone, which was reached at a depth of 590 feet. Examinations were made of samples collected on September 1, 1896. Percentage of nitrogen found: —

(1) 3.64.
(2) 3.61.

10. Well No. 12 of the Provincial Natural Gas Company at Sherkston, Canada. Gas is derived solely from the Medina Sandstone, which was reached at a depth of 850 feet.

The samples were collected on September 1, 1896. Percentage of nitrogen found: —

(1) 5.17.
(2) 5.10.

In the case of all these Canadian wells the gas samples were shipped at once to the laboratory, and the determinations made without delay. All the samples so far mentioned were taken directly at the wells. Several determinations of nitrogen have been made in the case of natural gas from the mains supplying Allegheny. This gas was derived from various wells scattered through a region of considerable area.

Date of Collection of Samples.		Percentage of Nitrogen found.
August 25, 1896	(1)	1.48
	(2)	1.50
August 26, 1896	(1)	1.52
	(2)	1.52
August 28, 1896	(1)	1.56
	(2)	1.54
August 28, 1896	(1)	1.52
	(2)	1.52
February 28, 1898	(1)	1.93
	(2)	1.99
March 9, 1898	(1)	1.30
	(2)	1.31

Careful tests for oxygen were made in the case of the gas from the mains, as there was a possibility of access of air to the gas. The method of testing consisted in causing the gas to bubble through a solution of manganous sulphate, to which a little sodium hydroxide had been added. A change in color of the manganous hydroxide which was precipitated would have indicated oxygen. Tests made in this way were continued frequently for an entire day while the nitrogen determinations were in progress, but no oxygen was found, and hence no air could have gained access to the gas.

There seems to be reason for the assertion that fluctuations occur in the composition of natural gas, but until the study of the subject is carried further, and more complete data obtained, no attempt can be made to connect such fluctuations with any known facts as to the geology of gas.

There is some little evidence for supposing that gas from the deeper horizons is richer in nitrogen, and that the older productive wells yield gas containing a little less nitrogen, but such may prove not to be the case when more data are at hand.

It seemed to be of interest to subject the incombustible gas residue, obtained in the preceding work, to further study. Portions of this residue were mixed with oxygen and subjected to the action of electric sparks. The experiments are still in hand, and their results will be presented in a later paper. It may be mentioned here that the gas subjected to this treatment yields oxides of nitrogen, and in presence of caustic alkali undergoes a considerable shrinkage in volume.

If natural gas occurs in liquefied form in the rocks owing to the

pressure to which it is there subjected, it is probable that when a drill taps the gas-bearing rock, causing relief of pressure, the more volatile among the constituents of the liquefied gas would escape in relatively larger proportion at the outset. The process occurring would be of the nature of fractional distillation, and would tend to the production of a gas especially rich in the most volatile constituent; but the most volatile constituent of natural gas is nitrogen, since all of the hydrocarbons and carbon dioxide would be more readily liquefied than nitrogen. The first yield of a gas well should therefore contain a higher proportion, relatively, of nitrogen, and this nitrogen should gradually diminish as the liquefied gas continued to evaporate. There would result after a time a gaseous mixture containing less and less of nitrogen, and when the reduction of pressure had progressed so far as to permit of the conversion of the least volatile of the constituents into gas, the proportion of nitrogen in the escaping gas would become constant, because the process would then be one of outflow of a gas mixture, and not of volatilization of an extremely low boiling liquid whose constituents have different boiling points.

If natural gas occurs liquefied in the rocks, we should expect to find that the newly drilled wells yield at first a gas relatively richer in nitrogen. The rock pressure in the Pennsylvania natural gas fields has in rare instances attained to 1,000 pounds per square inch. Some cases are reported in Northern New York State where rock pressures of 1,500 and 2,000 pounds have been measured. Such pressures are probably the highest ever observed in any natural gas field, but such pressures would be insufficient to liquefy natural gas. Should further determinations of nitrogen furnish evidence that a gradual diminution of the percentage of nitrogen is in progress, support would be given to the view that natural gas occurs in liquefied form in the rocks. The great productiveness of many single wells is, upon this supposition, more readily explained, for in the interstices of the rock might be stored a much larger quantity of gas if in liquefied form. The study of the composition of natural gas will have much to do with determining this point.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

SOME ELECTROCHEMICAL AND THERMOCHEMICAL RELATIONS OF ZINC AND CADMIUM AMALGAMS.

By Theodore William Richards and Gilbert Newton Lewis.

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BY THEODORE WILLIAM RICHARDS AND GILBERT NEWTON LEWIS.

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INTRODUCTION.

THE nature of amalgams, although a matter of much interest, especially in the light of the modern theory of solutions, is still obscure. The subject has been studied from the standpoint of electrochemistry by several investigators, notably by Meyer,* who observed the electromotive forces of cells of the following type: — Dilute zinc amalgam of concentration x; Solution of zinc salt; Dilute zinc amalgam of concentration y. Since the total change in a cell of this kind consists in the transfer of metal between amalgams of different concentrations, the electrical energy obtained is equal to the maximum osmotic work obtainable by the process. On the assumption that the zinc in the dilute amalgam obeys the laws of dilute solution, Meyer derived the following expression: —

$$E = 1.908 \frac{q}{M} T \log \frac{c_1}{c_2}; \tag{1}$$

in which E represents electromotive force; q, the electrochemical equivalent, in grams, of the metal carried in one second from one amalgam to the other; M, the molecular weight of the metal in the amalgam; T, the absolute temperature; $\log \frac{c_1}{c_2}$, the common logarithm of the ratio of concentration of the amalgams. By comparing with this formula the experimental results, Meyer showed with sufficient exactness that in dilute amalgams the molecules of the metals studied by him are monatomic. If, on the other hand, the atomic weight is substituted for M in the formula, the agreement between the calculated and his observed electromotive forces is not close enough to show whether the dilute

* Zeitschr. phys. Chem., VII. 477 (1891).

amalgams follow rigidly the laws of dilute solutions, on account of wide deviations in the observed values.

It has been the object of the present research to determine the electromotive forces of cells of the above type at varying temperatures, and with amalgams of all degrees of concentration, and also of similar cells in which one amalgam is replaced by the pure metal. Zinc and cadmium as metals, and normal solutions of their sulphates as electrolytes, were chosen as best adapted to the purpose. The experimental results were studied in relation to the two following equations: —

$$E = \frac{R}{ne_0} T \ln \frac{c_1}{c_2} = .000099\ T \log \frac{c_1}{c_2}. \tag{2}$$

$$\frac{dE}{dT} = \frac{E}{T} - \frac{Q}{ne_0 T}. \tag{3}$$

Equation (2) is the simpler form that (1) assumes when the atomic weight is substituted for M. E is the observed electromotive force; R is the gas constant; n, the valence of the metal in question ($n = 2$ in the case of zinc and cadmium); e_0 is the quantity of electricity in coulombs which is carried by one gram-equivalent; $\ln \frac{c_1}{c_2}$ is the natural logarithm of the concentration ratio. A comparison of this formula with the experimental results shows the extent of applicability of the laws of dilute solutions to amalgams (assuming the molecule of the metal to be monatomic when amalgamated).

Equation (3) is the Helmholtz equation for the temperature coefficient of a cell, where Q is the heat given off by the cell during a transfer of n gram-equivalents. In the cells under consideration the only change produced by the current is the transfer of metal from the solid electrode to the amalgam, or from one amalgam to another more dilute. Q then represents either the heat of amalgamation of n gram-equivalents (one gram-atom) of the metal, or the heat of dilution of an amalgam containing one gram-atom. The use of this equation permits the calculation of these quantities from the temperature coefficient of the cell.*

Since the heat capacity of the amalgam is approximately the sum of the heat capacities of its constituents, the heat of amalgamation is practically constant. If we place a constant, h, in place of $\frac{Q}{ne_0}$, equation (3) becomes

* Compare the interesting paper by Bugarszky, Zeit. anorg. Chem., XIV. 145.

$$\frac{dE}{dT} = \frac{E-h}{T}, \text{ or } \frac{dE}{E-h} = \frac{dT}{T},$$

integrating, $$ln\,(E-h) = ln\,T + C = ln\,KT,$$
where C is the integration constant and $C = lnK$, hence

$$E = KT + h. \tag{4}$$

Upon comparing this result with equation (3), which can be written $E = \frac{dE}{dT}T + \frac{Q}{ne_0}$, one sees that the outcome of this reasoning is simply the proof that if Q is constant $\frac{dE}{dT}$, (the temperature coefficient of the electromotive force) is also a constant. Thus the electromotive force of any cell of this type should be a linear function of the temperature.

Materials and Apparatus.

The materials used in this research were of known purity. The mercury had been twice distilled *in vacuo*. The zinc and cadmium were prepared by electrolysis from chemically pure salts. The zinc sulphate had been prepared in this laboratory for atomic weight investigation. The cadmium sulphate was prepared by dissolving the electrolyzed metal in pure sulphuric acid, and crystallizing twice in order to free it from the excess of acid. The amalgams were prepared by mixing weighed amounts of mercury and the metal used and diluting as desired. The amalgams were weighed and kept under solutions of their sulphates to prevent oxidation.

Both cadmium and zinc, when electrolyzed from ammoniacal solutions of their sulphates, separate in tree-like forms, varying according to the conditions of electrolysis from large and distinct crystals to finely divided spongy masses. The latter form is produced by the stronger currents and greater dilutions.

The metal thus made, after suitable washing, was sometimes dried with alcohol and ether and converted into amalgam, or sometimes used at once in the pure state in the trial cells. The method of using this spongy material as an electrode is described later, on page 90.

The vessels in which the measurements were made consisted of large H tubes, with their lower extremities drawn out and turned upwards. Platinum wires run in through these fine tubes established the connection with the galvanometer. It was occasionally convenient to use a double H tube, in which one electrode could be connected through the same electrolyte with either of two electrodes.

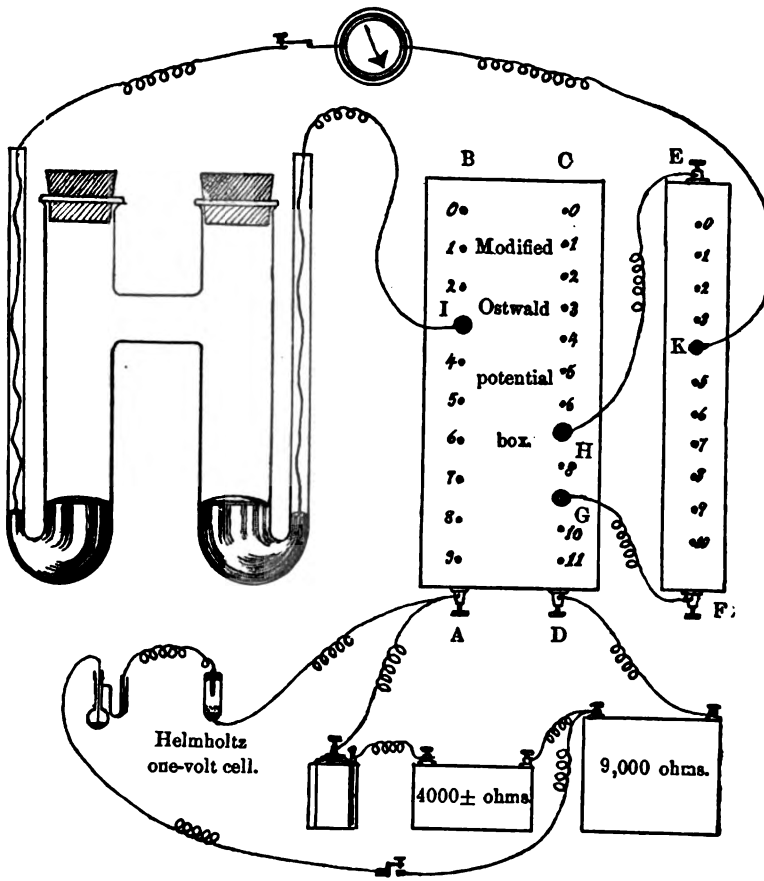

DIAGRAM OF APPARATUS.

The glass part at the left of the diagram is drawn about one third of the actual size. The remainder of the apparatus is not drawn to scale, being annexed merely to show the connections. For explanation, see page 91.

The cell was immersed in a thermostat which could be maintained constant at any desired temperature within one tenth of a degree.

The electromotive forces were measured by means of an astatic galvanometer according to the Poggendorff method. An Ostwald * "potential box," the resistances of which were carefully verified, was connected

* Ostwald, Hand- und Hilfsbuch, p. 252.

with a Leclanché cell through such external resistance as to maintain a total fall of potential of 0.1 volt. This was adjusted before each series of measurements by comparison with a standardized Helmholtz cell which remained constant in potential throughout the course of the experiments.

The direct measurement of potential as far as three figures when desirable was made possible by a device, the principle of which is shown in the accompanying diagram. *AF* represents a potential box containing three sets of resistances': *AB*, 9 times 100 ohms; *CD*, 11 times 10 ohms; *EF*, 10 times 2 ohms. These resistances are fitted with pegs for connection as in the ordinary potential box. *ABCD* forms a simple circuit between the terminals *A* and *D*. *EF* is a shunt whose terminals can be connected with movable caps to the pegs in the row *CD*. If they are connected to two pegs, *G* and *H*, for example, between which there is 20 ohms resistance, the current between the pegs is evenly divided by the shunt. Thus arranged the total resistance of *C—D* is 100 ohms, that of *A—B* is 900 ohms, making 1,000 ohms for the whole box. A definite potential is maintained between *A* and *D*. If for example this is 0.1 volt, then the fall between two adjacent pegs is in *AB* 0.01 volt; in *CD* 0.001 volt (except between *G* and *H*, where the total fall is 0.001 volt); in *EF* 0.0001 volt. The cell, *P*, whose potential is to be measured, is connected through the galvanometer to the box by means of the caps *I* and *K*. Its potential is compensated, and there is no current through the galvanometer when it is equal to the total fall from *B* to *I*, from *C* to *H*, and from *E* to *K*. This value can be read directly from the box; thus the arrangement in the figure indicates a potential of 0.0374 volts. Of course even the next decimal place may be estimated from the deflections of the galvanometer when two adjacent pegs in *EF* on each side of the true point are connected in succession, or might be measured directly by yet another shunt similar to *EF*, with a total resistance of four ohms. In this case *EF* must be provided with an extra peg.

The external resistance of 13,000 ohms was calibrated during the course of the experiments. Owing to an error found in this box, it was necessary to correct the direct readings of potential of some of the early cadmium amalgam cells by multiplying with a constant factor. The corrected readings are given below without comment.

Results.

Four classes of cells were studied: — (1) electrodes of cadmium amalgam of different concentration; (2) electrodes of zinc amalgam of

different concentration; (3) solid cadmium electrode opposed to cadmium amalgam; (4) solid zinc electrode opposed to zinc amalgam.

Class 1.

Table I. gives the values found for the electromotive forces of cells with electrodes of cadmium amalgams of different concentration. The lower extremity of each arm of the *H* tube was filled with amalgam to a depth of two or three centimeters, so that a fairly large volume might be present. Measurements were made at such temperatures that the amalgams were wholly liquid, for their partial solidification is an insidious cause of error capable of producing serious results, especially in this case of cadmium. The three per cent amalgam begins to freeze at about 0°, becoming wholly solid at a slightly lower temperature (about —3°); while the nine per cent amalgam is not wholly liquid until 45° is reached. For this reason measurements 10 in Table I. had to be made at high temperatures. Normal cadmic sulphate was the electrolyte.

TABLE I. Cadmium Amalgams.

	c_1	c_2	$\frac{c_1}{c_2}$	t	E (Obs.)	E (Calc.)	$\frac{E}{T}$
1	$\frac{1}{27}$	$\frac{1}{81}$	3	30	.01470	.0143	.0000485
2	$\frac{1}{9}$	$\frac{1}{27}$	3	30	.01470	.0143	.0000485
3	$\frac{1}{3}$	$\frac{1}{9}$	3	30	.01460	.0143	.0000482
				0	.01320	.0129	.0000483
4	$\frac{1}{3}$	$\frac{1}{9}$	3	30	.01445	.0143	.0000477
				0	.01303	.0129	.0000477
5	1	$\frac{1}{3}$	3	30	.01460	.0143	.0000482
				0	.01313	.0129	.0000481
6	1	$\frac{1}{3}$	3	30	.01450	.0143	.0000479
				0	.01313	.0129	.0000481
7	1	$\frac{1}{3}$	3	30	.01450	.0143	.0000479
				0	.01306	.0129	.0000478
8	1	$\frac{1}{3}$	3	30	.01450	.0143	.0000479
				0	.01306	.0129	.0000478
9	3	1	3	30	.01470	.0143	.0000485
10	9	3	3	72	.01993	.0163	.0000578
				60	.01915	.0157	.0000575

In the table, c_1 and c_2 represent the percentage by weight of cadmium in the amalgam, which in the case of dilute amalgams is proportional to the concentration by volume; t is the Centigrade temperature. The columns under E give the observed electromotive forces and those calculated from equation (2).

It was noticed by Meyer that the electromotive force of a cell of this kind increases rapidly upon standing. A similar effect was noticed by Jaeger* with solid cadmium amalgams. Although no explanation can be given of this phenomenon, one may prevent it by using as electrolyte a solution which has remained standing in contact with cadmium amalgam for several weeks before being used. The constancy thus reached permits much greater accuracy than could otherwise be obtained.

A study of the data of Table I. shows that the behavior of the last cell containing nine per cent amalgam differs materially from the rest. Regarding the electromotive forces of the other cells, it is to be noticed that, (1) at the same temperature they are all equal within limits of .0003 volt, therefore the potential depends on the ratio of c_1 to c_2, and not on their absolute values; (2) they are proportional to the absolute temperature; (3) they are uniformly higher than the values calculated from the formula, ranging from one per cent to three per cent too high. In the first two respects the amalgams obey rigidly the laws of dilute solutions. The small apparent deviation from these laws, indicated by the difference between the observed and calculated values, is therefore probably not a real deviation, but the effect of some slight side reaction in the cell.

The wide departure in the case of the last cell, on the other hand, shows that in amalgams of concentration as great as nine per cent there is a considerable deviation from the laws of dilute solution.

Theoretically, the nature of the anion of the electrolyte or the concentration of the kation should be without effect upon the result. This

TABLE II. VARYING ELECTROLYTES.

	c_1	c_2	t	E
$CdSO_4$ ($\frac{n}{1}$) . . .	1	$\frac{1}{9}$	30	.02925
$CdSO_4$ ($\frac{n}{10}$) . . .	1	$\frac{1}{9}$	30	.02915
CdI_2 ($\frac{n}{1}$)	1	$\frac{1}{9}$	80	.02920

* Wied. Ann., LXV. 106, 1898.

prediction was verified by experiment. Three similar cells were set up with different electrolytes, (1) normal cadmium sulphate, (2) tenth normal cadmium sulphate, (3) normal cadmium iodide. The results are shown in Table II. Theory demands 0.0286 instead of 0.0292.

Class 2.

The cells with electrodes of zinc amalgams were less constant in potential than those with cadmium, and the measurements were less trustworthy. Table III. gives the results with four cells of this type. The remarks on the preceding case apply here.

TABLE III. ZINC AMALGAMS.

	c_1	c_2	$\frac{c_1}{c_2}$	t	E (Obs.)	E (Calc.)	$\frac{E}{T}$
1	1	$\frac{1}{9}$	9	30	.02890	.0286	.0000954
				0	.02610	.0258	.0000956
2	$\frac{1}{3}$	$\frac{1}{27}$	9	30	.02920	.0286	.0000964
				0	.02625	.0258	.0000965
3	$\frac{1}{3}$	$\frac{1}{9}$	3	30	.01425	.0143	.0000470
				0	.01280	.0129	.0000469
4	$\frac{1}{9}$	$\frac{1}{27}$	3	30	.01515	.0143	.0000500
				0	.01365	.0129	.0000500

Class 3.

The measurement of the contact-potential of solid electrodes has always been subject to considerable uncertainty, due to accidents of crystallization, condition of surface, polarization, and other unknown causes. It seemed possible that by sufficiently increasing the extent and diversity of the surface an electrode might be obtained whose potential would be the mean of a large number of different values, and therefore constant. An electrode consisting of a quantity of finely divided metal perhaps a centimeter in depth, packed loosely around a sealed-in platinum wire seemed likely to satisfy the necessary conditions most nearly, and experiments made with zinc and cadmium electrodes of this sort yielded remarkably satisfactory results.

In order to justify the use of this solid electrode one must show that it always gives the same potential, and that this is equal to the true potential existing between metal and solution. The first experiments were made with a cell whose electrolyte was cadmium sulphate and whose electrodes consisted of electrolyzed cadmium, of medium fineness, which had been washed successively in dilute sulphuric acid, distilled water, and absolute alcohol, and then dried. The two electrodes being exactly similar, the electromotive force of the cell should be zero. The actual electromotive force, therefore, indicates the amount of deviation in potential of electrodes of this kind. Several such cells were measured. The largest electromotive force found was .0004 volt, the majority being about .0001 to .0002 volt. Better results were obtained with metal which, instead of being dried, was washed in the electrolyte. The difference of potential under these circumstances never exceeded .0001 volt when proper care was used in preparation. Moreover no greater difference was found when two electrodes made of entirely different samples of electrolyzed cadmium were used. Since, therefore, the same potential is obtained from such electrodes, whether the metal be in a finely divided spongy state, or consist of a coarser network of crystals, this may safely be considered the true potential of metallic cadmium. Similar experiments were made with zinc, with equally satisfactory results. The data given below illustrate the constancy of these electrodes. The electrodes were usually not tested for any considerable length of time, the cells being prepared anew for each series of observations, which only lasted a few hours. Table IV. gives the electromotive forces of cells where finely divided metallic cadmium was thus pitted against a dilute cadmium amalgam containing one per cent of cadmium.

TABLE IV. CADMIUM VERSUS AMALGAM.

	E at 0°	E at 24.45°
Cell No. 1 . . .	0.06835	0.07345
Cell No. 2 . . .	0.06830	0.07345
Cell No. 3 . . .	0.06845	0.07360
Cell No. 4 . . .	0.06835	0.07350
Average . . .	0.06836	0.07350

On referring to equation (4),

$$E = KT + h,$$

it is obvious that we have here data for calculating h; for

$$K = \frac{dE}{dT'} = \frac{0.07350 - 0.06836}{24.45} = 0.0002102.$$

Upon this basis, $h = 0.01096$. But according to our original definition $h = \frac{Q}{ne_0}$, or $Q = hne_0$. In this case $n = 2$, and $e_0 = 23040$, expressed in such units that if E is in volts, e_0E will be in gram calories. Hence we have

$$Q = +505 \text{ small calories.}$$

This result represents the small quantity of heat given off when one gram atom (or 112.3 grams) of cadmium is dissolved in 11,100 grams of mercury. The constancy of the quotient in the last column of Table I. shows that further dilution does not increase this heat evolution.

Class 4.

A further application of equation (4) is presented in Tables V. and VI., which give the electromotive forces of cells whose electrodes were of zinc and one per cent zinc amalgam. The cells were kept at each temperature for ten minutes after constancy was reached.

Between the observations (4) and (5) in Table V. the thermostat was raised to higher temperatures, but above 37° hydrogen bubbles were evolved at the solid electrodes and the electromotive force became inconstant. The thermostat was then cooled to 34.5° and the electrodes were stirred and shaken to drive off the accumulated hydrogen. The readings were then resumed.

In Table VI. between observations (7) and (8) forty-eight hours intervened; so that the later results are not so trustworthy as the earlier ones. These observations are not used in the calculation, but are given merely in order to show that even a long immersion in the electrolyte does not seem to affect very greatly the condition of the spongy zinc.

The equation, based upon the starred observations in Table V., is as follows:—

$$E = 0.0002000\, T - 0.04895.$$

Everywhere between 0° and 36° the values found agree almost exactly with the values calculated from this formula.

Here, as before, $Q = hne_0$; $n = 2$; $e_0 = 23040$; but in this case

$h = -.04895$. Therefore $Q = -2255$. That is, a gram atom of zinc (65.4 grams) takes up 2255 gram calories in dissolving in 6500 grams of mercury, or to greater dilution.

This method of determining thermal quantities is evidently one of great accuracy and convenience in cases where it is applicable. The data concerning the heats of amalgamation of zinc and cadmium which have previously been obtained are meagre. With these, however, the present results are in agreement. Thus Obach* found a cooling effect when zinc was amalgamated, a warming when cadmium was amalgamated. Favre † found for the heat of solution of amalgamated zinc 39.43 Kg-cal., for that of pure zinc 37.34 Kg-cal. The difference between the two represents the heat of amalgamation of zinc or —2100g-cal. The agreement of our result —2255 with this is striking.

The difference in potential between the solid metal and its saturated amalgam should be emphasized. It is often stated that the potential of

TABLE V. Zinc versus Amalgam.

	t	E (Obs.)		E (Calc.)
		(a)	(b)	
1	30.0	.01175	.01160	.01165
2	0.0	.00570‡	.00560‡	.00565‡
3	30.0	.01170‡	.01160‡	.01165‡
4	36.2	.01285		.01289
5	34.5	.01270	.01260	.01255
6	32.6	.01230	.01215	.01217
7	30.0	.01170	.01160	.01165
8	28.0	.01125	.01120	.01125
9	26.6	.01095	.01085	.01097
10	26.7	.01100	.01085	.01099
11	23.8	.01045	.01030	.01041
12	15.7	.00885	.00870	.00879
13	16.0	.00890	.00875	.00885

* Jahn, Grundriss der Elektrochemie, p. 8.

† Ibid.

‡ These values were taken as the basis of the formula.

TABLE VI. ZINC VERSUS AMALGAM.

	t	E (Obs.)		E (Calc.)
		(c)	(d)	
1	26.0	.01075	.01075	.01085
2	25.7	.01070	.01080	.01079
3	0.0	.00580	.00595	.00565
4	25.3	.01060	.01085	.01071
5	25.4	.01065	.01085	.01073
6	21.5	.00985	.01010	.00995
7	19.4	.00960	.00980	.00953
8	24.2	.01080	.01080	.01049
9	24.4	.01080	.01080	.01053
10	0.0	.00600	.00600	.00565
11	24.5	.01080	.01085	.01055
12	0.0	.00595	.00605	.00565
13	24.8	.01080	.01100	.01061

a saturated amalgam may be considered the potential of the pure metal. In the case of zinc this is true within a few thousandths of a volt; in the case of cadmium the difference between the solid metal and the saturated amalgam is 0.45 volt at 30°, and .054 volt at 0°.

SUMMARY.

The main points of the present paper may be summarized as follows: —

(1) A convenient method of measuring electromotive force directly to any desired number of decimal places is described.

(2) Cadmium amalgams as far as concentrations of three per cent and zinc amalgams to concentrations of at least one per cent obey closely the laws of dilute solution.

(3) The use of the Helmholtz equation for the temperature coefficient of a cell offers in these cases an accurate method of determining thermal quantities.

(4) The heat of amalgamation of cadmium is thus found to be +505 gram calories.

(5) The heat of amalgamation of zinc as thus found is —2255 gram calories.

(6) A solid electrode composed of finely divided electrolyzed metal gives a very constant and reliable potential.

(7) In the case of cadmium the contact-potential given by the saturated amalgam in reversible relation to an electrolyte differs by the twentieth of a volt from that given by the metal.

(8) In the case of zinc this difference is very slight.

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chloride was the cause of his failure to obtain trinitrophenylmalonic ester, although this does not appear from the statement in his papers.

Some experiments on the action of aniline on trinitrophenylbrommalonic ester yielded only viscous unmanageable products; and boiling it with water gave no more promising results.

We have also tried several times to detect the presence of trinitrobenzol in the secondary products of the action of sodium malonic ester on picrylchloride, but without success. It seems, therefore, that the replacement of the chlorine of the picrylchloride by hydrogen does not take place under these conditions to any great extent, if it occurs at all.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY
OF HARVARD COLLEGE.

ON CERTAIN DERIVATIVES OF SYMMETRICAL TRICHLORBENZOL.

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BY C. LORING JACKSON AND F. H. GAZZOLO.

Presented October 12, 1898. Received October 20, 1898.

IN a paper by Sidney Calvert and one of us,* the behavior of tribromiodbenzol $Br_3 1,3,5,I2$, and of tetrabrombenzol $Br_4 1,2,3,5$, with sodic ethylate was studied, and it was shown that the atom of iodine (or the atom of bromine in the corresponding position) was replaced by hydrogen under these conditions, giving the symmetrical tribrombenzol. It seemed of interest in this connection to study the corresponding trichlor compounds, that is, the trichloriodbenzol and the trichlorbrombenzol, to see whether the loosening effect of the three chlorine atoms might not be even greater than that of the three atoms of bromine, and thus make it possible that these substances would react with other agents beside sodic alcoholates, which were the only reagents that had any such effect upon the bromine compounds.

At that time it was not worth while to undertake the work, because of the great difficulty in preparing symmetrical trichloraniline, but since this obstacle has been removed by the beautiful method of Victor Meyer and Sudborough,† we have prepared these compounds and studied some of their relations. Trichloriodbenzol, $Cl_3 1,3,5,I2$ melts at 55°; and by treatment with sodic ethylate dissolved in alcohol and benzol yielded symmetrical trichlorbenzol recognized by its melting point 64° and two analyses. It therefore behaved like the tribromiodbenzol under these conditions. All our other attempts to obtain a simple replacement of the iodine in this substance failed, so that it is no more reactive than the tribromiodbenzol. Fuming nitric acid converted the trichloriodbenzol into the trichlordinitrobenzol melting at 129°, iodine being set free.

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* These Proceedings, XXXI. 123.
† Ber. d. chem. Ges., XXVII. 3151.

The trichlorbrombenzol $Cl_3$1,3,5,Br2 melts at 65°, that is, at nearly the same temperature as the symmetrical trichlorbenzol 63°.4 (Körner), and what is strange, higher than the corresponding trichloriodbenzol. With sodic ethylate it lost bromine, but the reaction was not specially studied. When treated with fuming nitric acid it gave a trichlorbromdinitrobenzol melting at 175°, which was a decidedly reactive substance. Aniline replaced the three atoms of chlorine, giving the trianilidobromdinitrobenzol $C_6(C_6H_5NH)_3Br(NO_2)_2$, melting at 175° to 176°, discovered by W. D. Bancroft and one of us.*

Sodic ethylate also acts upon it, probably giving a number of products, to judge from analogy and the fact that both sodic bromide and sodic nitrite were detected among them, but we have only succeeded in identifying one of these with certainty; this is a bromdinitroresorcine diethylether melting at 81° to 82°, and probably having the following constitution, $(OC_2H_5)_2$1,3,Br2$(NO_2)_2$4,6, although it may be that one of the ethoxy groups stands at 5 instead of 3. It must have been formed by the replacement of two atoms of chlorine by two ethoxy groups, and the third by hydrogen. As in most of the replacements of a halogen by hydrogen it has been found that it stood between two nitro groups, we think there can be little doubt that the first constitution assigned to this body is the correct one. Its formation is interesting, as it is the first case we have found in which chlorine has been replaced by hydrogen under these conditions. In all the other cases studied the chlorine has remained unaltered, or has entered into some simple reaction: thus picrylchloride gave picryl ether,† picrylmalonic ester,‡ or picrylacetacetic ester, § according to the reagent used; chloranil gave dichlorquinonedimalonic ester, ‖ or, so far as the replacement alone was concerned, dichlordiethoxyquinone; ¶ and trichlordinitrobenzol gave dichlordinitrophenylmalonic ester,** or chlordinitroresorcine diethylether, and dinitrophloroglucine triethylether.†† These last cases are especially striking, since the corresponding tribromdinitrobenzol showed a replacement of bromine by hydrogen, when treated with sodium malonic ester or sodic ethylate.

* These Proceedings, XXIV. 293.

† Jackson and Boos, These Proceedings, XXIII. 176.

‡ Jackson and Soch, Ibid., XXX. 401.

§ Dittrich, Ber. d. chem. Ges., XXIII. 2720.

‖ Stieglitz, Am. Chem. Journ., XIII. 38.

¶ Kehrmann, J. prakt. Chem., [2], XL. 367; Jackson and Grindley, These Proceedings, XXX. 430.

** Jackson and Lamar, Am. Chem. Journ., XVIII. 775.

†† The same, Ibid., p. 668.

This bromdinitroresorcine diethylether, melting at 81° – 82°,

$$(OC_2H_5)_2 1,3, Br2, (NO_2)_2 4,6 ?$$

is isomeric with those melting at 184°,

$$(OC_2H_5)_2 1,5, Br3, (NO_2)_2 2,4,$$

and at 92°,

$$(OC_2H_5)_2 1,3, Br5, (NO_2)_2 2,4,$$

made by the action of sodic ethylate on the symmetrical tribromdinitrobenzol.

The trichlorbromdinitrobenzol also reacted with sodium malonic ester but we were unable to bring the product into a state fit for analysis. When the dry substance was treated with sodic ethylate, it gave a deep vermilion product, which probably belongs to the class of colored compounds formed by sodic ethylate and certain nitro bodies,* as it was decomposed by water and some organic solvents. This is the first case, so far as we can find, in which one of these substances has been observed derived from a compound of benzol with all its atoms of hydrogen replaced by other radicals.

Trichloriodbenzol, $C_6H_2Cl_3I$.

To prepare this substance 17 grams of sublimed trichloraniline (made by the excellent method of V. Meyer and Sudborough †) were mixed with moderately dilute sulphuric acid in the proportion of one molecule of trichloraniline to each molecule of sulphuric acid, and after thorough cooling powdered sodic nitrite was added in small successive quantities, until the nitrous fumes generated were no longer absorbed. After each addition of the sodic nitrite the flask was corked and vigorously shaken, until all the red fumes were absorbed, taking care that the contents were kept cool throughout the operation. When a sufficient amount of sodic nitrite had been added, the mixture was filtered, the cooled filtrate freed as completely as possible from the excess of nitrous fumes by vigorous shaking, and then treated with a distilled aqueous solution of hydriodic acid, until there was no further action. The brownish precipitate thus obtained was washed first with a solution of potassic iodide to remove free iodine, and finally with water, after which it was purified by sublimation, or by crystallization from hot alcohol, until it showed the constant melting point of 55°. It was dried *in vacuo*, and gave the following results on analysis: —

* These Proceedings, XXXIII. 173, and Amer. Chem. Journ., XIX. 199, where a complete list of the papers on this subject is given.

† Ber. d. chem. Ges., XXVII. 3151.

0.2188 gram of the substance gave by the method of Carius 0.4746 gram of a mixture of argentic chloride and iodide. After washing this precipitate with ammonic hydrate 0.1672 gram of argentic iodide were left undissolved.

	Calculated for $C_6H_2Cl_3I$.	Found.
Chlorine and Iodine	75.94	76.10
Chlorine	34.69	34.73
Iodine	41.30	41.29

The substance is therefore trichloriodbenzol, and as it was made from common trichloraniline its constitution must be $Cl_3$1,3,5,I2.

Properties of Trichloriodbenzol. — It crystallizes from alcohol in white slender needles terminated by one plane at a very acute angle; these needles are often a centimetre or more long, and are much branched, the branches forming a sharp angle with each other and developing into forms like feathers. It melts at 55°, and sublimes easily. It is freely soluble in ether, benzol, chloroform, acetone, carbonic disulphide, or ligroin; soluble in ethyl or methyl alcohol, when cold, more freely soluble when hot; soluble in glacial acetic acid; insoluble in water, cold or hot. A mixture of alcohol and chloroform is the best solvent for it. It is apparently unaffected by the strong acids, or by sodic, potassic, or ammonic hydrate.

Behavior of Trichloriodbenzol with Sodic Ethylate.

Two grams of trichloriodbenzol dissolved in anhydrous benzol were mixed with 20 c.c. of an alcoholic solution of sodic ethylate made from one gram of sodium, and the mixture was allowed to stand over night. The liquid turned dark brown, and a precipitate began to separate soon after adding the ethylate. To make certain that the reaction was complete, the mixture was heated on the steam bath in a flask with a return condenser, which rendered the brown color much darker. The product was then evaporated to dryness; during the evaporation an odor like that of an aldehyd was observed, but the presence of one could not be determined by other tests. The dry residue was treated with water, and the insoluble portion separated from the solution, which gave tests for an iodide. The portion insoluble in water, which was very dark brown, was washed thoroughly, and then purified by crystallization from alcohol, until it showed the constant melting point 64°, which proved that it was the symmetrical trichlorbenzol. This was confirmed by the following analyses of the substance dried *in vacuo*: —

I. 0.0906 gram of the substance gave by the method of Carius 0.2154 gram of argentic chloride.

II. 0.0792 gram of the substance gave 0.1862 gram of argentic chloride.

	Calculated for $C_6H_2Cl_3$.	Found. I.	II.
Chlorine	58.68	58.78	58.13

Behavior of Trichloriodbenzol with Other Reagents.

With aniline even at its boiling point trichloriodbenzol showed no signs of action, except that the color of the mixture became darker, and a certain amount of turbidity appeared, but no test for an iodide could be obtained, and the trichloriodbenzol was recovered unaltered.

When trichloriodbenzol was heated on the steam bath for three hours with an aqueous solution of sodic hydrate, the liquid took on a chrome-yellow color, but this must have been due to a very slight reaction, as after acidification it gave no precipitate with argentic nitrate, and essentially the whole of the trichloriodbenzol was recovered unaltered.

Melted sodic hydrate, on the other hand, seemed to act upon it, as a brownish mass was obtained, which after solution in water gave a slight precipitate on acidification and a reddish solution; a good test for an iodide was obtained, but the yield of the new organic substance was so small that we did not study this reaction further, since at best it seemed to us of slight interest.

Sodium malonic ester had little or no action on the trichloriodbenzol, most of which was recovered unaltered from the product, so that the hope of obtaining enough of a substance (if one were really formed) for analysis was so small that we did not continue work in this line.

From these experiments it appears that the trichloriodbenzol is no more reactive than the tribromiodbenzol, from which exactly similar results were obtained by Sidney Calvert and one of us.*

When trichloriodbenzol was mixed with nitric acid of specific gravity 1.50 and strong sulphuric acid, and the mixture gently heated, the solid went into solution. It was allowed to stand at ordinary temperatures over night, and then precipitated with a large quantity of water, when a mixture of a white body and scales of iodine was thrown down. The iodine was recognized by its crystalline form, color, smell, and purple fumes. The white body was purified by crystallization from alcohol,

* These Proceedings, XXXI. 128.

when it showed the melting point 129°, and is therefore the trichlordinitrobenzol $Cl_3 1,3,5,(NO_2)_2 2,4$.

Trichlorbrombenzol $C_6H_2Cl_3Br$.

Twenty grams of trichloraniline dissolved in 100 c.c. of hot glacial acetic acid were mixed with 90 c.c. of hydrobromic acid (boiling at 125°), and, disregarding the heavy grayish yellow precipitate, the mixture was thoroughly cooled in an ice bath, and then treated with powdered sodic nitrite, until red fumes were given off freely. The sodic nitrite was added in small quantities at a time, and the flask containing the mixture shaken vigorously after each addition, the liquid being kept cool throughout. The heavy precipitate already mentioned went into solution during the addition of the sodic nitrite, forming a dirty yellow liquid. After standing for a few hours to complete the reaction, the contents of the flask were poured into an evaporating dish, and heated for an hour on the steam bath. In this way a dark oily product floating on the surface of the liquid was obtained, which solidified on cooling. The mother liquor deposited more of this product in a semi-crystalline condition, and an additional amount was obtained from it by heating it again with more hydrobromic acid. The product was purified by sublimation followed by recrystallization from alcohol, until it showed the constant melting point 64°–65°. As this is the same as the melting point of trichlorbenzol, we supposed at first that our product was this body, but the following analyses of the substance dried *in vacuo* showed that it was the desired trichlorbrombenzol.

I. 0.1618 gram of the substance gave by the method of Carius 0.3850 gram of the mixture of argentic chloride and bromide.

II. 0.1116 gram of the substance gave 0.2656 gram of the mixture of argentic chloride and bromide.

III. 0.1276 gram of the substance gave on combustion 0.1274 gram of carbonic dioxide and 0.0108 gram of water.

	Calculated for $C_6H_2Cl_3Br$.	Found. I.	II.	III.
Chlorine and Bromine *	71.60	71.76	71.74	
Carbon	27.64			27.23
Hydrogen	0.77			0.94

* By a curious coincidence the results of analyses I. and II., if calculated as argentic chloride, give numbers agreeing excellently with the percentages calculated for $C_6H_3Cl_3$, so that the combustion was necessary to determine whether our compound was this, or the $C_6H_2Cl_3Br$ which has the same melting point.

The yield of trichlorbrombenzol was 12 grams, instead of the 26.5 grams which should have been obtained from 20 grams of trichloraniline, that is, over 45 per cent of the theory.

Properties of Trichlorbrombenzol. — It crystallizes from alcohol in white radiating needles, which develop into long slender blunt ended prisms. It melts at 64°–65°, that is, one degree higher than the symmetrical trichlorbenzol, which melts according to Körner at 63°.4; not only is this coincidence striking, but it is also surprising that it should melt at a higher temperature than the trichloriodbenzol, which melts at 55°. It sublimes easily. It is freely soluble in ether, benzol, or acetone; soluble in cold alcohol, more freely in hot; soluble in glacial acetic acid, or ligroin; less soluble in methyl alcohol, and still less in carbonic disulphide. The best solvent for it is alcohol. The three strong acids have no apparent action on it, but fuming nitric acid converts it into trichlorbromdinitrobenzol, as described later. When a benzol solution of the trichlorbrombenzol was treated with sodic ethylate, the atom of bromine was removed, as was shown by testing the wash waters from the product for bromine, when a strong reaction for it was observed.

Trichlorbromdinitrobenzol $C_6Cl_3Br(NO_2)_2$.

To prepare this substance the trichlorbrombenzol was mixed with nitric acid of specific gravity 1.52 and one third the quantity of strong sulphuric acid, and the mixture heated gently for an hour. At first the solid dissolved, but later the nitro compound was deposited from the solution. After the mixture had stood over night, the supernatant acid was poured into a large quantity of water, which gave an additional amount of the product. It was purified by crystallization from a mixture of alcohol and benzol, until it showed the constant melting point 175°, when it was dried *in vacuo*, and analyzed with the following result: —

0.1654 gram of the substance gave according to the method of Carius 0.2914 gram of the mixture of argentic chloride and bromide.

	Calculated for $C_6Cl_3Br(NO_2)_2$.	Found.
Bromine and Chlorine	53.21	53.10

The constitution of this substance is settled by the method, in which it was made as $Cl_3 1,3,5, Br 2, (NO_2)_2 4,6$. The yield is essentially quantitative.

Properties of Trichlorbromdinitrobenzol. — It forms, when crystallized

from alcohol and benzol, thick rather blunt rhombic plates, the obtuse angles of which are frequently bevelled by two planes. They show a tendency to form groups with the members superimposed, and have a slight yellowish tinge. The substance melts at 175°; and is very soluble in chloroform, acetone, or carbonic disulphide; slightly soluble in ethyl or methyl alcohol either cold or hot; insoluble in cold, soluble in hot glacial acetic acid; essentially insoluble in ligroin, or in hot or cold water. The best solvent for it is a mixture of benzol and alcohol. Strong hydrochloric or sulphuric acid has no apparent action on it. Fuming nitric acid dissolves it when hot. It sublimes easily, and in this way feathery ivory-white crystals are obtained sometimes over a centimeter in length.

Action of Aniline on Trichlorbromdinitrobenzol.

When one gram of trichlorbromdinitrobenzol was warmed gently with a slight excess of freshly distilled aniline, it went into solution forming a cherry-red liquid, the color of which became deeper on longer heating. To obtain the product the liquid was poured into a large quantity of water, acidified with hydrochloric acid, and the crimson precipitate formed in this way thoroughly washed, and crystallized from a mixture of alcohol and benzol, until it reached the constant melting point 175°–176°. This showed that the substance was the bromdinitrotrianilidobenzol $C_6Br(NO_2)_2(C_6H_5NH)_3$ obtained by W. D. Bancroft and one of us* from tetrabromdinitrobenzol and aniline. In this case it was formed by the replacement of the three atoms of chlorine by three anilido groups.

Behavior of Trichlorbromdinitrobenzol with Sodic Ethylate in the Cold.

Five grams of trichlorbromdinitrobenzol dissolved in anhydrous benzol were mixed with the sodic ethylate made from twenty-five grams of absolute alcohol and one gram of sodium, which gave the proportion of three molecules of the ethylate to each molecule of trichlorbromdinitrobenzol. The two substances reacted at once, since the liquid took on a bright scarlet color as soon as they were mixed, and there was also a slight evolution of heat. To complete the reaction the mixture was allowed to stand three days at ordinary temperatures, during which time a heavy precipitate was deposited, and the color changed to a yellowish red. The precipitate was filtered out, washed with alcohol, and then dissolved in water. This solution gave a strong test for sodic nitrite with

* These Proceedings, XXIV. 293.

potassic iodide, starch paste, and dilute sulphuric acid, and also a heavy white precipitate with argentic nitrate and nitric acid. To obtain the organic products of the reaction the reddish alcoholic filtrate was allowed to evaporate spontaneously, and the residue treated with water; the insoluble substance thus obtained was purified by crystallization from alcohol, until it showed the constant melting point 81°–82°, when it was dried *in vacuo*, and analyzed with the following result: —

I. 0.1236 gram of the substance gave by the method of Carius 0.0684 gram of argentic bromide.

II. 0.2500 gram of the substance gave 18.4 c.c. of nitrogen at a temperature of 23° and a pressure of 754.7 mm.

	Calculated for $C_6HBr(C_2H_5O)_2(NO_2)_2$.	Found. I.	II.
Bromine	23.89	23.56	
Nitrogen	8.36		8.24

The substance is therefore a bromdinitroresorcine diethylether formed from the trichlorbromdinitrobenzol by the replacement of two atoms of chlorine by ethoxy groups, and of the third by hydrogen. Certain points in regard to its constitution are settled, since the two ethoxy groups must be in the meta position to each other, and the atom of bromine and the two nitro groups are in the symmetrical position to each other. The radicals therefore are probably arranged as follows,

$$(C_2H_5O)_2 1,3, Br 2, (NO_2)_2 4,6,$$

but it is possible that one of the ethoxy groups instead of the atom of hydrogen stands at 5 between the two nitro groups. It is isomeric with the bromdinitroresorcine diethylether melting at 184°, and made by Warren and one of us * from tribromdinitrobenzol and sodic ethylate in the cold, which has the constitution $(C_2H_5O)_2 1,5, Br 3, (NO_2) 2,4$, and also with that melting at 92° obtained by Koch and one of us, † as another product from the same reaction, which has the constitution

$$(C_2H_5O)_2 1,3, Br 5, (NO_2)_2 2,4.$$

The yield of the bromdinitroresorcine diethylether was one gram from five of the trichlorbromdinitrobenzol, that is, about 21 per cent of the theoretical yield.

* These Proceedings, XXV. 166. † These Proceedings, XXXIV. 128.

Properties of Bromdinitroresorcine Diethylether, melting at 81°–82°, $C_6H(C_2H_5O)_2Br(NO_2)_2$.

It forms when crystallized from alcohol white needles or slender prisms terminated by two planes at an obtuse angle to each other, which turn brown on exposure to the light. It melts at 81°–82°, and is very soluble in benzol, or chloroform; soluble in methyl alcohol, acetone, glacial acetic acid, or carbonic disulphide; slightly soluble in cold ethyl alcohol, more soluble in hot; slightly soluble in ligroin. Alcohol is the best solvent for it. It is not acted on apparently by strong hydrochloric acid, either hot or cold; strong sulphuric acid does not act in the cold, but when warm dissolves it with a brownish red color; strong nitric acid does not act in the cold, but gives a colorless solution with it when hot.

That this bromdinitroresorcine diethylether was not the only organic product of the reaction of sodic ethylate on trichlorbromdinitrobenzol was shown by the fact that sodic nitrite as well as sodic chloride was formed. Our attempts to isolate these other bodies, however, were far from successful. Some experiments with the aqueous wash waters seemed to indicate that they contained a phenol melting at 111°, and having perhaps the formula $C_6(OC_2H)_2OH(NO_2)_2Br$, but the analytical data obtained were too imperfect to justify a description of the body; and we did not succeed in bringing any of the other products into a state fit for analysis.

The trichlorbromdinitrobenzol seemed to give colored compounds with sodic ethylate similar to those given by picrylch oride and several other nitro compounds, since upon adding an alcoholic solution of sodic ethylate to the dry substance it took on a strong vermilion color, which was instantly destroyed by water, and more slowly by benzol or ligroin. The fact that the color disappeared on the addition of water indicates that it is one of the colored compounds under discussion, and not a salt of a phenol. Another sample of the color was allowed to stand for half an hour exposed to the air, at the end of which time the red color had given place to yellow. As the colored compound was less stable than several others which have been studied, its investigation was not carried further.

The trichlorbromdinitrobenzol is acted on by an alcoholic solution of sodium malonic ester. Our first experiments gave a crystalline product, but in too small quantity for analysis. Our later experiments have yielded only viscous masses, from which we have not succeeded in obtaining anything for analysis in spite of a very large expenditure of time and material.

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SHORELINE TOPOGRAPHY.

By F. P. Gulliver.

SHORELINE TOPOGRAPHY.*

By F. P. Gulliver.

Presented by W. M. Davis, October 12, 1898.
Received October 29, 1898.

"When I have seen the hungry ocean gain
Advantage on the kingdom of the shore,
And the firm soil win of the watery main,
Increasing store with loss and loss with store;
When I have seen such interchange of state,
Or state itself confounded to decay;
Ruin hath taught me thus to ruminate."

Shakespeare, Sonnet LXIV.

INTRODUCTION.

Physiographic Standpoint. — The present paper deals with the development of coasts from a geographic standpoint, and attempts to work out the criteria by which we may determine whether a given coastal area stands now at a relatively higher or lower level with reference to the level of the sea than it did in some previous cycle or portion of a cycle. Particular emphasis will be laid upon the stages of development, which follow each other according to dynamic laws in a systematic succession, both after uplift and after depression. The time since the beginning of the cycle or epicycle † is found to have a very important bearing upon the question of continental oscillation. The dynamic forces of nature do not leave the initial forms produced by uplift or depression, but produce a successive series of sequential forms, which may be used, when the order of the normal succession is apprehended, as criteria to determine the time since the cycle began.

Omitted Phases of the Subject. — The shoreline, the line formed by the intersection of the plane of the sea with the land, is in a geographic sense a most inconstant line. Though for the geographic minute, a

* This paper was written for the Doctorate of Philosophy at Harvard University, and was presented in June, 1896. It has been condensed and slightly revised for publication. September, 1898.

† See p. 154.

generation of men, it is practically in the same position, yet even in the short period of historic time records show that villages have been submerged, or that seaport towns have been turned into inland places. The historical side of this problem is not to be here discussed, nor is the cause of the secular movements of the earth's crust, including the question of isostasy, here considered.

As dwellers upon the land, we look at the change in the relative position of land and water as it affects our position. Thus "the land rises," "the coast sinks," are the common expressions of man. If the point of view was that of the inhabitants of the sea, the expressions would be reversed, the sea sinks when the land rises and rises when the land is depressed. It will be convenient in this paper to use the terms elevation, uplift, emergence, raised, etc., and their opposites, depression, submergence, sunken, etc., in reference to the land. Such use is not intended to imply a limitation of movement to the land, excluding that of the sea floor, but is to describe the geographic effects from the standpoint of man, who lives upon the dry land.

The shrinking of the mass of oceanic waters will also cause the land apparently to rise to the same amount all over the world.*

By the draining of lakes many characteristic forms of shore development will be exposed, which are here classed with forms following uplift; while the increase of water in a lake for any cause will give the same forms as are produced by a depression of the land.

The relation of the accumulation of glaciers to changes of elevation, and the evidence afforded by coral islands to show rising or sinking regions, are two problems for solution which are not attempted by the present writer.

Use of Terms. — Throughout this paper the author uses *shoreline* for the line of intersection of the sea with the land. The region immediately to the landward of the shoreline is called the *coast*, and seaward from this line the *shore*. Thus cliffs and deltas are coastal features, while waves advance and retreat along the shore.

In the figures the older mainland is cross-hatched, while forelands are left blank. The observer is supposed to look from the point of view of the sea as it attacks the land, therefore the two sides of the figures will be spoken of as the right and left respectively as seen from the sea looking toward the land.

* The effect in inland seas with imperfect outflow has been discussed by Prof. Suess, Anzeiger d. k. Akad. d. Wiss., 1887, XXIV. 180–182.

Initial is here used as the technical term to define the form at the beginning of any geographic cycle or epicycle. Any dynamic process which produces a change in the relative position of land and sea may interrupt a cycle at any stage of development, and introduce a new cycle. Later stages and forms will be called *sequential*. These terms are offered to avoid the misconception, on account of their vernacular meaning, of the terms *constructional* and *destructional*, sometimes used for the identical ideas.

Previous Work on Shorelines. — Since the days of Strabo and Aristotle, two of the greatest observers among early geographers, much has been added to the science of geography. Passing over the work * of the cartographers, explorers, and speculative writers, mention must be made of the great mass of facts collected by Ritter and Humboldt and of their use by Guyot; but the great outdoor observer, De la Beche, whose work was the stock in trade of the next generation, first interpreted many of the coastal forms. He in 1834,† and Dana more fully in 1849,‡ recognized land-carved forms under water, or drowned valleys, as proof of depression of the land. Robert Chambers recognized raised beaches and associated coastal forms, and showed that the Atlantic coastal plain indicated elevation.§ Lyell with his doctrine of uniformity, Ramsay with the theory of marine denudation, the Geikies, LeConte, Darwin, and many other geologists, have worked out the changes in form of coasts here grouped under various sequential stages.

Members of the United States Surveys, Bache, Mitchell, Gilbert, Shaler, Whiting, Davidson, and others, have worked out many of the details of coastal forms and their changes, and a large number of observations recorded upon maps and charts have been the basis of much of the work in this paper.

In 1879, Dr. Hahn discussed the rising and sinking of coasts, but he did not consider the ratios between activities nor take into account the time since which a given movement took place. Weule, Cold, Keller, and Sandler have also studied shorelines, but the fullest discussion of coastal and shore forms has been made by von Richthofen and his pupil, Dr. Philippson.‖

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* See Lyell, Prin. Geol., 11th ed., 1872, 22, 57; Woodworth, Am. Geol., 1894, XIV. 210.

† Theoretical Geology, 192–194.

‡ Geology of the Wilkes Expedition, 1849, 677.

§ Ancient Sea Margins, 221, 253, 270, 276, 299.

‖ See list of references for these and other papers.

PART I. INITIAL FORMS.

1. The Geographic Cycle.

Systematic Sequence of Forms. — Before the consideration of the initial forms themselves is undertaken, the position of the initial stage in relation to geographic cycles of development must be clearly understood. Consequently at the outset some of the general facts of cycles will be discussed in their bearing upon the problem of stages in the development of shorelines, and particularly as regards the initial or first stage of a cycle.

In this paper many facts from different sources are brought together, and the attempt is made to show some of the laws of coastal development. After the inductive study of coast forms upon the better mapped areas of the world had been made, and the deductive scheme of development worked out, gaps in the scheme were found which are not filled by examples. This lack of facts to fit ideal cases may be because they do not exist upon our small earth, or because they have not been reported, as well as on account of a defective scheme. By showing where such gaps in our theoretical scheme of development occur at present, the eyes of future field workers may be sharpened to look for the expectable facts.

Succession on Land. — Land forms go progressively through a series of successive stages of development, to which have been applied names taken from various stages of life, thus suggesting that forms as seen to-day began as something else, and will as time advances become systematically still further developed. Stages of the cycle follow one another from birth to death in the ideal case, where the land stands still long enough for the completed development. The initial stage, or birth, is succeeded in turn by infancy, youth, adolescence, maturity, past-maturity, old age, and finally by death.

A new cycle is inaugurated by each oscillation of any considerable amount, minor changes of level being included as epicycles, or divisions of a cycle. Land forms advance successively from infancy toward old age in each cycle, while any stage of development may be arrested by elevation or depression of the land and a second cycle begun. An essential conception is that a region will be finally reduced to a peneplain if the baselevelling action of the streams, and the other forces of subaerial degradation, be allowed to continue long enough to reduce the land forms to extreme old age. Insequent, consequent, subsequent, and obsequent streams all play their part in the development of the land forms, captures of one stream by another follow unequal chances, while super-

posed streams often come unexpectedly upon a difficult piece of work. Any one unacquainted with the details of this scheme, as worked out by Professor Davis, will be referred to the articles given below.*

Succession on the Coast. — At the beginning of a cycle the subaerial forces of degradation enter upon a new piece of work. Similarly the sea has to begin anew its attack upon an initial coast. A series of coastal forms would be expected to result, and these may be grouped in stages analogous to those of land forms. On account of the many variables which control topographic form, it would not be expected to find the inland area and the coast of the same region in homologous stages of development. The general surface of a coastal plain may be in youth or maturity when its coastline has advanced to adolescence. Because the coastline has reached an adolescent stage of development, it does not follow that the surface of the coastal plain further inland is also in adolescence.

The initial stages of coast and inland surface begin together, for both are controlled by a relative change in position of land mass to sealevel. In making out the initial and sequential stages of shore development from an inductive study of coasts and shores, the writer has tried to follow the principles used by Professor Davis in his studies of the stages of land forms, aided by his critical suggestions during the progress of the work.

The thesis of this paper is: THE FORMS OF ANY COASTAL BELT MAY BE GROUPED IN THE APPROPRIATE STAGES OF A CYCLE. THESE FORMS WILL BE CONSISTENTLY RELATED TO THE ASSOCIATED LAND AREA ON THE ONE HAND AND TO THE SEA BOTTOM ON THE OTHER. WHEN CONSIDERED TOGETHER, THE FORMS OF A COASTAL BELT INDICATE THE RELATIVE TIME SINCE THE LAST CONSIDERABLE UPLIFT OR DEPRESSION, AS WELL AS THE RATIO EXISTING BETWEEN THE SEVERAL ACTIVITIES, IN THEIR DYNAMIC EFFECT UPON THE FORMS OF THE COAST AND THE SHORE.

Rising, raised; sinking, sunken. — In considering any of the consequences of continental oscillations, care must be taken to discriminate between the movement of the land during historical time or the geographic to-day, its movement during the immediate past of geographic time, and the last movement of any considerable amount. Because there is good evidence of either a geologic or a geographic character, that a given land has moved either up or down during the period of more careful observa-

* Nat. Geog. Mag., 1889, I. 12–26, 183–258. Proc. B. Soc. Nat. Hist., 1889, XXIV. 365–423. Am. Nat., 1889, XXII. 566–583. Bull. G. S. A., 1891, II. 541–586. Geographical Illustrations, Harvard University, 1898.

tion of the last century, it does not follow, from such observations *per se*, that the land has moved in that same direction for any length of time previous to the earliest of said observations; and moreover, if in addition to such demonstrated recent movement there exists geologic or geographic evidence to show earlier motion in the same direction, such cumulative evidence of motion in one direction is no valid argument for continued motion in the same direction, for any period of time longer than that required by the nature of the evidence itself. The converse of this proposition is also true, viz. that evidence which shows that a country has been raised or sunken does not prove that the region has been rising or sinking in recent time, or is to-day rising or sinking.

That the time element has been left out of the majority of previous considerations of shorelines, in the discussion of their elevation or depression, will be clearly perceived by any one who will go over the literature of the subject.

Areas of Elevation and Depression as Mapped. — A comparison of three maps of "rising" and "sinking" regions will show how different points of view have led to opposite conclusions. Dr. G. R. Credner considers the presence of large deltas a proof of slow rising, therefore in his map of changes of level * he regards all regions of great deltas as rising. In contrast with Credner's map, compare that of upheavals and depressions by Reclus.† In this map, "drawn after Chas. Darwin," all regions where the coral growth is prevailingly of the atoll and barrier reef type are given as sinking, while those regions where the fringing reefs occur are mapped as regions of upheaval. Thus the hypothesis of Darwin, ‡ who regarded the form of coral construction as evidence of "probable subsidence" and "probable elevation," when given such definiteness as upon the map of Reclus, makes a striking contrast to the map by Dr. Credner; many "rising areas" on the one are "sinking areas" upon the other. Neither of these two criteria can be safely used to show present or recent movement, nor are they more than hypothetical suggestions of earlier changes of level.

Scandinavia on both of these maps is given as rising, because of its raised beaches and "water-marks." This peninsula. as will be shown later, is in the larger geographic sense in a cycle of development following depression.

An interesting historico-geographic study could be made by a com-

* Pet. Geog. Mitt., Erg. Nr. 56, 1878, Tom. III.

† La Terre, 1872, I. 702, Pl. XXIV.

‡ The Structure and Distribution of Coral Reefs, 3d ed., 1889, Pl. III.

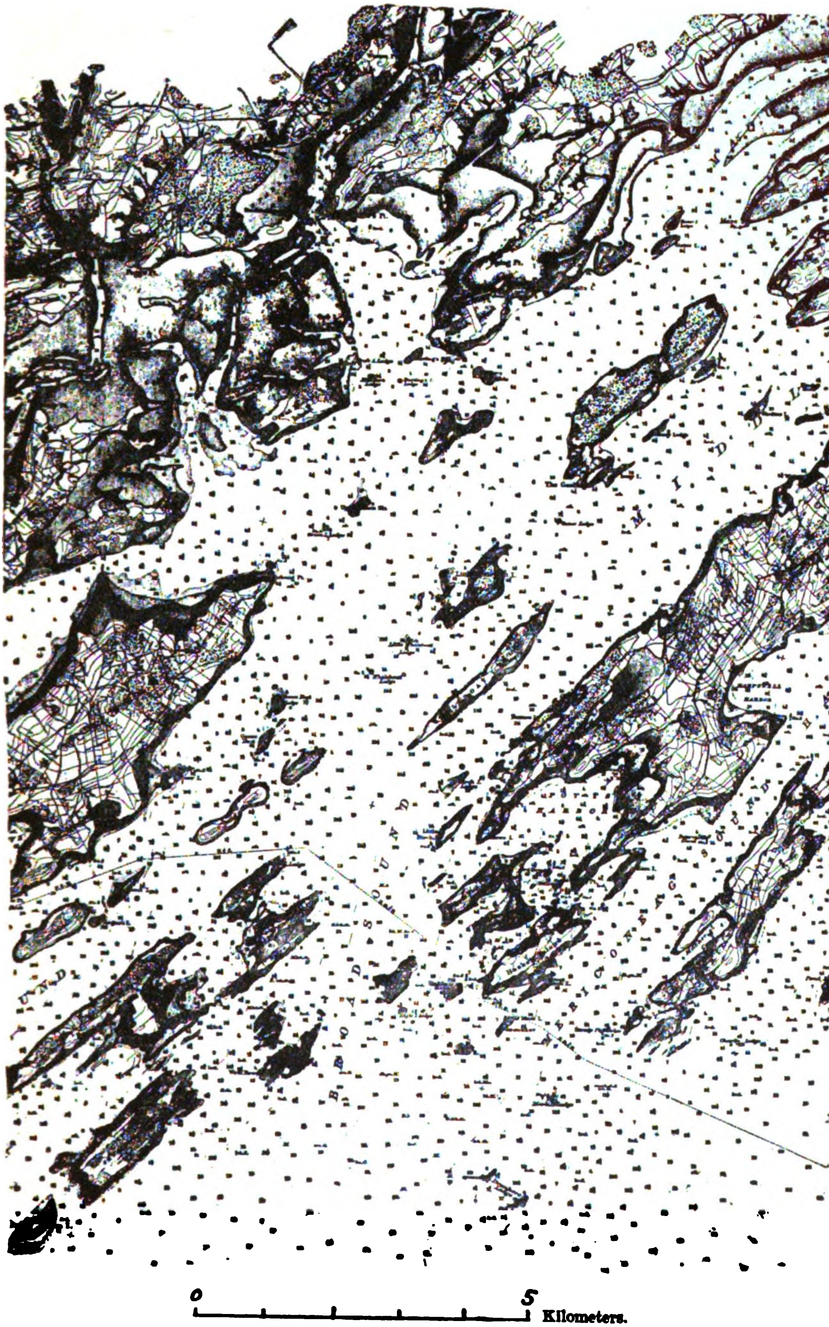

FIGURE 1. Casco Bay, Maine. Drowned Topography in Youthful Stages of Development. (Sheet 815, U. S. C. G. S.)

parison of the facts used as criteria of rising and sinking in central and southern Europe. For our present purpose, however, it will suffice to indicate how loosely criteria have been interpreted. Compare the two maps referred to above with that of France by Girard.* Each of the three differs from both of the others. Southwestern France, the Landes coast, is given by Credner as sinking, by Reclus as rising, and by Girard as sinking in some places and rising in others.

Algebraic Sum of Movements: Maine. — The position of the land in the present cycle is determined by the algebraic sum of all past oscillations. The form is due to development in ($n + 1$) cycles. Cycles and epicycles previous to the present may be recognized in inverse proportion to the time since their close, and in direct proportion to the stage of development reached in said cycle or epicycle. A region is classed in this paper, as in a certain stage of development following elevation or depression, according to the larger facts of form prevailing in the region.

For example, the coast of Maine (Figure 1) is on the whole a depressed region. It has numerous islands, bays, etc., showing drowned topography in a youthful stage of development. At Ogunquit,† however, as well as in other parts of this area, are seen criteria of elevation, elevated shore-line, narrow coastal plain, nip, lagoon, and enclosing offshore bar. Since the greatest depression, there has been an episode of elevation. The development of the sequential features, following the initiation of a new cycle of depression, has been interrupted by this episode or epicycle of elevation.

FIGURE 2. Diagram showing Mutual Relations of Cycle, Epicycle, and Vibration.

Cycle, Epicycle, and Vibration, New Jersey; Scandinavia. — It is only to the larger movements of the land to which the term cycle is applicable. The minor ups and downs of the coast are but portions of a cycle, each of which may be called an epicycle, which in turn may be made up of various smaller swings or vibrations. The relations of these various movements to one another is shown in the accompanying diagram (Figure 2).

* Soulèvements et depressions du sol sur les côtes de France, Bull. Soc. Géog., 1875, X. 225, et la carte.

† See pp. 185, 188.

Professor Salisbury has given us a very pretty example of such epicycles in his Beacon Hill and Pensauken subdivisions of the Yellow Gravel of New Jersey, and of what we may term vibrations in the Jamesburg and later subdivisions.* He has found it possible to determine from the geographic form and position of the deposits the change of level of the coast, though the changes are relatively so small that the evidence of movement cannot be traced far inland. It is possible, on the other hand, to trace the Tertiary peneplain for a considerable distance into the interior, where for instance it is seen in the floor of the Great Valley; while the Cretaceous peneplain is the great surface of reference for geographic features in the eastern United States. These cycle features must not be regarded as the result of some sudden massive uplift, but rather as the summation of minor vibrations and epicycles, during which the average position of the land was such as to cause the Tertiary and Cretaceous peneplains.

Scandinavia (Atlas Univ., 29, 30) is a good example to show the differences between cycle, epicycle, and vibration. Taken as a whole, the peninsula is a depressed region, some portions being deeper drowned than others. Two typical areas will illustrate this. The form of the region around Stockholm (Swe., 67, 68, 75, 76, 77, and adjacent sheets, Swe. Geol., 50, 51, 52, 53) indicates that it was maturely dissected in the previous cycle, and is now submerged to a greater and greater amount out from the shore, as is shown by the large islands near shore, the smaller islands off shore, and the minute islets and skerries out in the Baltic. Baron de Geer makes the axis of greatest uplift in the recent episodes of elevations in the central portion of Scandinavia.† This tilting, at whatever time it occurred, is indicated by the increasing relief in certain directions of the topography of this area.

The second region is in central Norway (Nor., 45, C, D; 46, C, D; 48, B; 49, A, B, C, D; 50, A, B, C, D; 52, B, D; 53, A, C, D; 56, A, B). This area shows adolescent dissection of the upland, the land being more continuous than in the first region mentioned.

While in a large geographic way the Scandinavian peninsula is a depressed area, there have been epicycles of elevation in which terraces have been cut. ‡ Recent vibrations are also shown by changes of water level at the established water-marks (R. Seiger).

* Ann. Rep. State Geol. N. J., 1893, 35–328.

† See references.

‡ See papers by Brögger, Chambers, de Geer, Högbom, Kjerulf, Lyell, Miller, Möhn, Munthe, Pettersen, Reusch, Sandler, Sexe, and Sieger.

Episodes of depression occurring after those of elevation or alternating with them, if they occurred, must have been of short duration, as well as those of elevation, for there is no indication that the development of coastal features has continued for a great length of time at any level since that at which the adolescent to mature dissection took place. A possible exception to the above is the short cycle represented by the rock bench called by Dr. Reusch "the coast plain" (Nor., 6, B; 45, C, D; 46, C; 48, B; 49, A; 53, C; 56, A, B). From the form it is impossible to tell whether this was cut before or after the deepest valley dissection, shown by the present fjords. In his English summary (the writer is not able to read the Norwegian paper) Dr. Reusch says, "It has been worked out in periods previous to the glacial period, and in the intervals of that time." * If it is later than the deeper dissection some traces of the material filling the bays should be found, though the glaciers would have carried off most of the loose detritus.

Volcanic and Climatic Accidents. — In this paper the shore features that result from the accidents, *volcanic* and *climatic*, which are not an essential part of the normal cycle, are not considered in detail. With the general scheme of the normal development of shorelines following elevation and depression in mind, a study of the accidental interruption of the normal succession can profitably be made. The volcanic features as shown in Etna (Italy and Sicily, 269, 270, etc.), and Santorin (Fouqué, Santorin et ses éruptions, Paris, 1879) and the glacial features as seen on Öland island (Swe., 17, 22), in Boston harbor (C. S., 337), Greenland, and Alaska; and the arid coasts of Arabia and the shores of the Red sea, etc., all furnish an attractive field for special study.

Geographic and Paleontologic Criteria. — By the emphasis laid on geographic criteria for the recognition of change of level and time since the initiation of a new cycle, it must not be inferred that the writer implies any lack of confidence in the value of evidence from the position of life forms. Geography and paleontology should go hand in hand in showing past changes of level, as where one fails the other may avail. While historically paleontology has had the lead, perhaps the more natural leader would be geography; then the indications, given by the inductive study of the form of a region, may be confirmed by its contained fossils.

Ideal Areas. — Two areas of strongly contrasted conditions are taken as types. In each area the development of coastal forms has been considered to have advanced to late adolescence or into maturity in the previous

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* See references.

cycle. In the first area the land is supposed to have risen with respect to the water far enough to bring all the features of shore development of the previous cycle above baselevel; while in the second area these features are depressed beneath baselevel. Criteria are worked out for these two normal or average conditions, and later other possibilities will be considered in connection with actual regions.

2. Uniform Uplift.

Initial Stage of an Ideal Area. — Let it be conceived that a region be elevated as a unit to a certain distance above sealevel. The geologic cause of such uplift need not be considered here, as this paper treats of

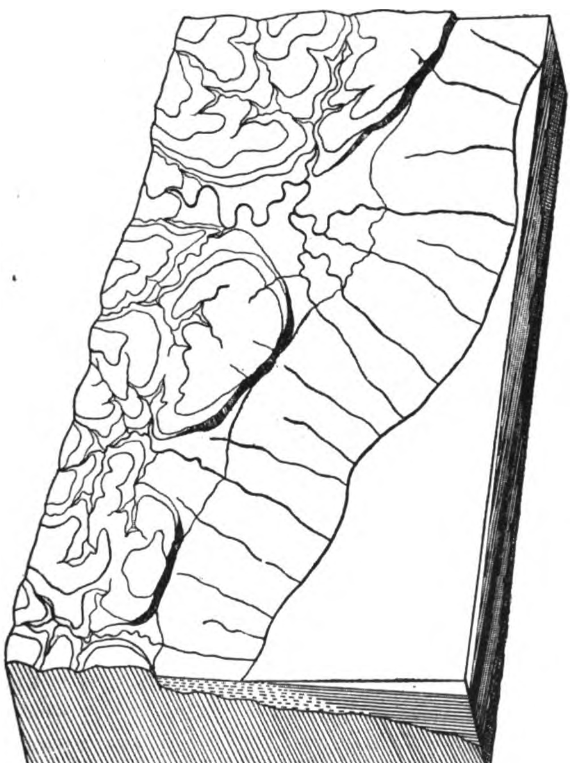

Figure 3. Ideal Block in Initial Stage following Uniform Uplift. Such a Region shows Smooth Bottom, Simple New Shoreline, Smooth Coastal Plain, Elevated Former Shoreline, and the Dissected Oldland.

the geographic results of continental movements. Enough that it be granted as a possibility of geology that such uplift of a land mass may take place.

The form of the land at the initiation of a new cycle of development is a most important consideration, and it is one which is most frequently left out of the discussions of elevation and depression. The form of the land at the beginning of a cycle depends upon the stage of development reached in the previous cycle, as well as upon the amount and rate of uplift. The ideal case here considered is taken where a coast of homogeneous structure had been developed to late adolescence or early maturity in the previous cycle, and the uplift was supposed to have been sufficient in amount to bring all the coastal and shore forms, developed in the previous cycle, considerably above sealevel; and this uplift took place, not suddenly, but steadily, so that the sea did not have time to appreciably attack the land while it progressively rose. A diagrammatic representation of the resulting form is given in Figure 3. The forms of the shoreline and of the inland and seaward areas will each be separately considered.

(1) *Smooth Bottom.* — The waste from the land, brought down by the streams or worn off the coast by the waves, would have been spread out by the currents in the previous cycle, thus causing the bottom to be smooth out from the new shoreline. In the ideal case which we are here considering, the bottom would consist of the finer waste of the previous cycle, where the sea currents had built it up into the continental delta, at a depth below the deepest wave attack. Such sedimentation in the previous cycle would have filled any irregularities then existing, so that the bottom offshore from the initial shoreline would be monotonously level or gently undulating.

(2) *Simple New Shoreline: Buenos Ayres.* — Where the ocean or other large body of water now intersects the land there will be initial shore features. At first before the waves have had time to attack the coast the outlines will be simple, the land gently sloping toward the sea and ending in broad, undulating curves, probably convex where large rivers enter. As the initial land surface would have but a slight dip seaward, it having been formed under water, the sea would leave exposed at low tide a wide area of flats. The most marked feature in this new born shoreline is its slight crenation and long curves. It would take but a faint convexity of the land surface to give a convex shoreline.

The Argentine Republic southeast of Buenos Ayres has a shoreline upon a gently sloping land, very nearly flat. Before the present chan-

nel was dredged to enable ships to reach the city, the steamers had to discharge their freight into lighters, and these in turn to wagons driven into the water. This region appears to be the one least advanced at present beyond its initial stage, and is therefore given as the best example known to the writer of an initial shoreline following elevation. There is no good account of this coast, the fragramentary hints given by travellers being the only descriptions which we have; and the poor maps (H. C., 616, 930) show little else of coastal and shore forms besides the gently swinging shoreline.

(3) *Smooth Coastal Plain: Texas.* — A coastal plain ought to be found along the margin of the uplifted area, wider where there had previously been an extensive continental shelf, narrower where less waste had been deposited in the previous cycle; but with its inner margin at practically the same height on all sides of the elevated mass. Consequent drainage would characterize this uplifted shelf, while extended rivers from the oldland would flow across the coastal plain as master streams.

The coastal plain of Texas, according to the account given by Professor Penrose,* is a flat plain with the streams lying almost upon the surface, which has a gentle seaward slope. This plane surface appears to be nearly in its initial stage of development. The surveyors report that there is "nothing to map" in this coastal plain area. The shoreline is not consistently related to the surface of this coastal plain, for it has suffered since the elevation a slight episode of depression, as is indicated by the narrow bays, where the sea has entered the lower portion of the valleys, which the coastal plain streams had begun to widen.

(4) *Elevated Former Shoreline: San Clemente*, Figure 4. — At the inner margin of this coastal plain we should find shoreline features younger or older according to the conditions of development of the region before its uplift, but at a practically uniform elevation above the sea at the present time. Reasonable variations in the height of the beach as formed must be expected, but such variations will have to admit of explanation as formed by one water level, as under this head of uniform uplift no differential elevation is understood.

Any of the sequential coastal or shore forms, which will be discussed in Part II., may be found at the level of the former shoreline, and the stages to which these several forms had advanced in the previous cycle should now be found consistently related to each other and to the old-

* First Ann. Rep. Geol. Sur. Texas, 1889, 5–101.

land. The cliff, rock bench and terrace, beach, bar, etc., may all be found elevated above the sea in this initial stage of the new cycle. A good example of a recently elevated shoreline is not known to the writer.

Figure 4, giving a portion of San Clemente island, California (C. S., 607, 671, now 5100, 5127), shows several elevated former shorelines, the last formed being nearly in their initial stage. For detailed description of these cliffs and terraces, resulting from periods of comparative quiet in a series of progressive uplifts, consult the account of the island by Professor Lawson.*

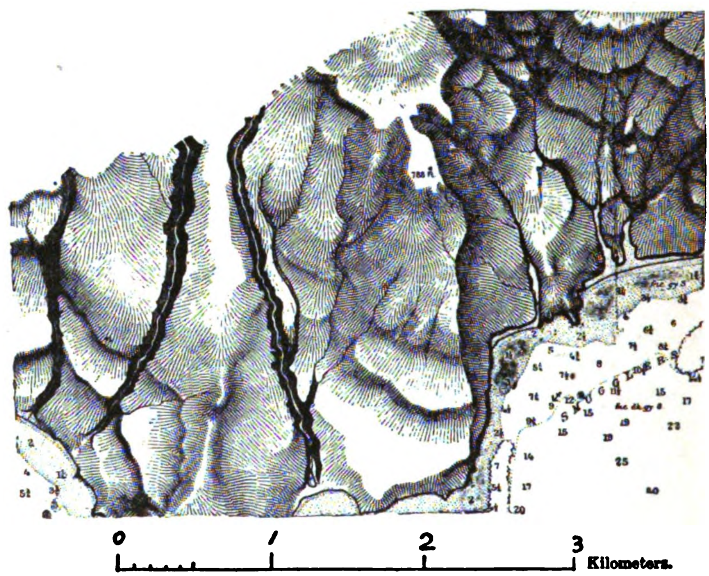

FIGURE 4. Elevated Former Shorelines on San Clemente Island, California.

One of the features characteristic of progressive uplift is clearly shown upon this map, namely, the more advanced stages of stream development farther and farther inland from the shore. The valleys widen as one ascends from the western shoreline, and are shallower on the lower terraces, as is seen on the map. The streams have had more time in which to dissect the higher terraces.

The sequential forms, developed at each level on this island, indicate extreme youth at the time of each uplift; therefore the coastal plain

* Bull. Dept. Geol., Univ. of Cal., 1893, I. 128–133.

and offshore deposits, characteristic of an area uplifted after mature development, which was the condition assumed in the discussion of the ideal area, are not here found. The gently sloping terraces have but scanty covering of waterworn pebbles.*

(5) *Dissected Oldland.* — Upon either hand, as one stood at such a raised beach in the ideal area under consideration just after it had been elevated, strongly contrasting regions would present themselves. Below, the faintly seaward-sloping plain; while above would be seen the dissected oldland. No general criteria for all regions can be given, for the aspect which a given country at this time will present depends entirely upon what stage of development was arrested by its change of position with respect to baselevel. Young, mature, composite, or forms of almost any other possible stage, may be found. The question for the observer to ask is, Where in its path of life did this country stand?

Variations from Ideal Scheme. — Many variations from this ideal scheme will at once suggest themselves. The land may have been depressed but a short time before the uniform uplift occurred, and then the bottom would not have been smoothed over. The coast may have been so steep that all the waste from the cliff cutting was dumped immediately offshore from the rock bench, and only a narrow terrace was formed in continuation of the bench. This is practically the case in San Clemente and in the raised beaches of Scandinavia, already referred to (pages 159, 160), where no broad coastal plain, simple new shoreline, nor smooth bottom is found.

Variations in structure will cause great differences in the coastal and shore forms. A mountain region with its structure transverse to the shoreline, as is the case in Brittany, will show, after an uplift following adolescent dissection, a much more irregular elevated shoreline than in the ideal case of homogeneous structure considered above. A region of longitudinal mountain structure, like the Austrian coast (page 168), would show its characteristic features of development in its elevated shoreline.

Time since the last considerable movement is however the most important factor to be considered in regard to variations from the ideal scheme. If the previous cycle had advanced only to youth, the coastal and shore forms, seen after the uplift in the elevated shoreline, would have the characteristic forms of youthful development. In this case it would be easy to tell whether the second cycle previous to the present was one

* *Loc. cit.*, p. 132.

following elevation or depression, for as will be shown later the forms in the various stages are quite different, as far at least as into maturity. After maturity is reached in the development of forms of the coast and shore, the distinction between a cycle following uplift and one following depression is not so marked.

Slow and rapid Movement. — The initial criteria for the ideal case have been given as if the land were raised at once to a certain height and then stopped, and as if its form were exactly as it had been when developed at a lower level. Such a conception is of course admissible in an ideal scheme, but in the consideration of actual examples the sea will generally be found to have done some work while the movement was in progress. A series of halts may be made in the upward movement, as has been shown in San Clemente (Figure 4). Any speed of uplift may be found in a given locality, and the above criteria must be modified to fit the case under consideration.

Regional and Continental Uplift. — From the uplift of a limited area we may extend the conception to a whole continent, but we must be careful that the criteria are found throughout the whole of the area in which the uplift is inferred. If a whole continent was uplifted bodily, the new shoreline, the coastal plain, and the elevated former shoreline should be found all round its margin, unless some local reason could be given for the absence of one or more of these criteria in a given locality.

Continental movements have been inferred from local phenomena, particularly by writers who have discussed the relations between elevation and glaciation, so that the term as found in the literature is used in a very loose way.

3. Uniform Depression.

Initial Stage of an Ideal Area. — As in the case of uniform uplift an ideal case will be first considered in the study of the initial forms following uniform depression. The ideal case is taken of a region of homogeneous structure, which was developed to early maturity in the previous cycle, and the depression was sufficient to entirely submerge all the forms of the coast and shore developed in the previous cycle. The depression is regarded as having been continuous, though not necessarily rapid. The sea action upon the land during the slow depression was not sufficient in such a short space of time to materially change the mature forms of the previous cycle.

(1) *Uneven Bottom.* — If a region be submerged for a certain amount beneath the sea, the vertical distance being the same on all sides, the

subaerially carved topography would be partly under water. The inequality would be proportionate to the relief of the land still exposed, the change from the more even offshore bottom of the former sea area to the uneven floor of the submerged area being less abrupt the more gradual the depression.

Criteria of submarine form have been very loosely used by writers in the past. In some cases the same facts have been used to prove diametrically opposed theories. Compare the use of inequalities of the bottom by Dr. Spencer and M. Bertrand, the one to prove subaerial denudation in the West Indies at a former greater elevation, while the other considers all such irregularities in the English channel as the result of warping. *

All along the Atlantic shore of the United States, from Maine to North Carolina, submerged channels have been revealed by the detailed soundings of the Coast Survey; and on the Pacific shore Professor Davidson has shown many channels which are not continuations of present river systems. Many of these are however undoubtedly the result of warping, and all have been more or less cloaked over with land waste, so an example surely in an initial stage following uniform depression cannot be given. An example, which comes as near as any known to the writer to being still in a very youthful condition since depression, is in the bay of Maine (C. S., 103, 104, 105, 106), where the soundings indicate very marked submarine channels, which are continuous with land valleys. A small portion of this area is shown in Figure 1.

(2) *Irregular New Shoreline: Scandinavia.* — The intersection of the sea with the uneven land surface produces an irregular shoreline, possessing many drowned valleys or rias † and arms of the sea between headlands and islands. The degree of irregularity depends upon the strength and variety of relief of the submerged area and on the amount of submergence.

For any given area, it is probable that there is a certain medium measure of submergence which will give a maximum irregularity of shoreline. The slopes above and below the water level will be essentially identical, inasmuch as the shoreline lies at a level independent of the form of the land.

The excessive irregularity of a drowned shoreline is well illustrated by the coast of Scandinavia. The coast of Maine (Figure 1) is less irregular, both on account of a less mature dissection before drowning and also

* See references. † See p. 220.

because this coast is further removed from its initial stage. Puget sound (C. S., 6450, 6460) shows an irregular shoreline with many branching bays, but much more work has been done in this locality since the drowning to simplify the shoreline. Mr. Willis has shown * that this region is complicated by faulting.

(3) *Dissected Land comparable with Submerged Topography: Austrian Coast.* — In from the coast the land would have for its initial form one which is appropriate to the stage of the former cycle, which was interrupted by the relative depression of the land with respect to the sea. The whole region has been supposed to move together, so the streams fit their valleys; therefore if it were not for the many streams now pointing into the same bay, "betrunked" and entering the sea independently, it could not be told from their individual action in the present cycle that their work had been diminished by the submergence.

The type example of drowned longitudinal topography, now in an exceedingly early stage of development since the initial submergence, is the Adriatic coast of Austria (Austr., Zone 24, col. IX, X, XI; 25, IX, X, XI, XII; 26, IX, X, XI, XII; 27, X, XI, XII; 28, XI, XII, XIII; 29, XI, XII, XIII; 30, XII, XIII, XIV; 31, XIII, XIV).

The cliffs on the more exposed land are older than where better sheltered. It is a region of Mesozoic and Eocene strata of the Jura or Appalachian type of folding, maturely dissected when drowned, into whose longitudinal valleys the sea has entered, forming characteristic drowned valleys of the longitudinal type. † In many places the slopes intersect the sea level without a trace of having been attacked by the sea since the depression. Following these slopes under water we sometimes find them continuous with the unsubmerged portion, while in other places the soundings indicate a rapid change from steep to gentle grades. A detailed geological map with sections showing the structure of the Jurassic, Cretaceous, and other strata is needed to show whether these rapid changes of slope under water are due to structure, to baselevelling, or to aggradation during a slow depression. The central portions of the sounds and channels bordered by the inner shoreline have broad flat areas ranging in depth from 70 to 95 meters.

The general accordance of level of these bottoms suggests as the most

* Chi. Jour. Geol., 1897, V. 99.

† See various articles in Austrian journals by the following geologists: Bittner, A.; Hauer, Franz Ritter v.; Hilber, V.; Petermann, A.; Stache, Guido; Tietze, Emil; and Toula, Franz.

probable explanation of their origin that they represent the areas reduced close to baselevel during the previous cycle, when the land mass stood higher and was dissected to maturity. Such lowlands would be slightly cloaked over during a gradual submergence. Such slow depression is indicated by the bays almost filled by deltas with no bay-bars at their mouths. A period of gradual sinking, slow enough to allow delta growth to fill the valleys as they went under water, and fast enough to prevent much cutting of cliffs and building of bars, would account for the existing combination of initial shoreline with bays nearly delta filled.

Infantile islands, minutely irregular shoreline, projecting headland, and unfilled bays are characteristic of the southern portion of this area. The depression has no doubt varied slightly in time and amount in different portions of this region, but as a whole it is a remarkably good example of drowned topography close to its birth.

Other Examples. — A few other examples of drowned topography that have advanced but slightly from their initial stages are here given, with but a word of comment in the several cases. Special features in these areas which show an advance from the initial condition are considered later under the several headings in Part II. All these regions taken together with Austria, the type of longitudinal drowned topography, give an idea of the various types of forms resulting from the drowning of subaerially carved topography. In several cases the depression may not have been absolutely uniform.

The beautiful Christiania river system developed to adolescence before drowning (Nor., 9, A, B, C, D; 10, A, B, C, D; 14, B, D; 15, A, C; 19, B, D; 20, A).

The meandering valley form of Kolding fjord argues strongly for submergence of subaerially carved topography (Denm., Fredericia, Bogense, Skamlings Banke).

The meandering valley above Haderslebener lake is continued in Haderslebener fjord with swings of proportional radius of curvature (Germ., 7, 12, 13).

The drowned valley of the Warnow river below Rostock is about the same size as that above the city (Germ., 86).

Greece and the coasts of the Ægean sea (Atlas Univ., 40; Attica; maps in Der Peloponnes). Dr. Philippson has shown in his monograph on the Peloponnesus that this region is dissected into many blocks by diastrophism.* This causes rocks of differing resistance to be near one another; thus on this account, and also because of the stronger sea action in certain places, one finds adolescent development replacing the more common youthful forms upon the coasts to the north.

Clarence strait, Revillagigedo channel, and Portland canal, Alaska, show the typical ramifications of subaerially carved topography (C. S., 8100, 706).

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* Der Peloponnes, 418–432.

Variations. — As in the case of uniform uplift (p. 165) there will be great variations from this ideal scheme of criteria for uniform depression. The stage of development interrupted by the drowning, the steepness and structure of the coast, and the rate of submergence, all have important bearing upon the form of the depressed coastal and shore forms. Slow sinking while the sea cuts into the land will materially aid the formation of a planation surface. Professor von Richthofen goes so far as to consider all regional plains of abrasion, "Abrasionflächen," as necessarily the work of the sea aided by slow submergence.*

The gradual depression and cloaking over of a region are the normal results of the isostatic return to a condition of equilibrium. Stripping in one area and loading in another causes a lack of balance, which will be restored by a rising of the stripped, and a sinking of the loaded area. One of the best examples of isostasy is seen in the Mississippi basin.†

Now while the principle of isostasy explains some regions of slow depression with concomitant sedimentation, it does not account for the more pronounced changes of level, introduced by secular elevation or depression. Geographic cycles are not introduced by isostatic movements. The suggestions of cause are numerous, but these geological questions are not considered in this paper. The subject is here dismissed with the statement, made by Major Dutton, that "the nature of the process is, at present, a complete mystery." ‡

4. Diverse Movements.

Tilting; Position of Pivotal Axis. — Uniform uplift and depression have been considered, and the resulting initial forms contrasted in the two cases. If, instead of a uniform uplift throughout the area, the movement is diverse, we have tilting, warping, or crumpling and faulting. If the change of quantity proceeds at a constant rate, we have rigid tilting; if at a variable rate, but of moderate variety, we have warping; while if much irregularity of rate appears, we have disorderly crumpling or faulting.

With the exception that the topographic forms are elevated or depressed to different amounts in various places, the criteria of tilting are the same as those already discussed. Tilting may be of such a character

* Führer für Forschungsreisende, 1886, 354.

† See the following articles: McGee, A. J. of S., 1892, XLIV. 177–192; Bull. G. S. A., 1894, VI. 55–70; Keyes, Bull. G. S. A., 1894, V. 231–242.

‡ Phil. Soc. Wash., 1889, XI. 63, 64.

as to give criteria of uplift in one portion of the tilted region and those of depression in another.

The former shoreline in a tilted region, unless the axis of tilting was parallel to the general direction of the coast, would not be level, as it was found to be in a region uniformly uplifted. It will be progressively higher away from the axis on the side of elevation, and will be more irregular in height the more sinuous the shoreline before the tilting took place. The raised beaches around lake Ontario, taking Dr. Spencer's elevations of the Iroquois beach, show a very nearly even tilt.

The position of the pivotal axis, as pointed out by Professor Shaler,* gives differing results, and thus the criteria differ for the several cases. The pivotal axis may lie parallel to the coast, at right angles to it, or in any intermediate position. This axis may be at the shoreline, inland from the coast, or seaward from the shore. The tilting itself may be of two kinds; either the seaward slope may be increased, or diminished. These various possibilities will cause many variations in the quantity and quality of the criteria.

Topography of Tilted Regions: California; New England. — A two-cycle history of a region, in which an uplift occurs between the first and the second, causes the development of composite topography. When, however, the uplift is not uniform, a new element comes in; the topographic forms developed after a tilt are not only composite, but are also inclined with respect to baselevel. Those forms of land, which were developed with reference to one spheroidal plane when it coincided with baselevel, are tilted, so that this spheroidal plane of the first cycle forms throughout the region a constant angle with the plane of the sea in the second cycle. The first cycle of course may be in any stage of development when the tilt is made, but the recognition of the tilt will be progressively easier the later the stage reached before tilting.

A peneplain extends north for a hundred miles from about the fortieth parallel to the great bend of Pit river, California.† This plain is tilted at an inclination of 100 feet to the mile toward the east, and is canyoned by streams 300 to 400 feet deep, which have not yet reached grade. "The cañons in general are deepest to the westward and gradually run out to the Sacramento river in the newer deposits which fill the valley. It is evident that since the baselevel was formed, it has been affected by

* Mem. B. Soc. Nat. Hist., 1874, II. 337.

† J. S. Diller, Jour. of Geol., 1894, II. 32–54; 14th Ann. U. S. G. S., 1892–93, Pt. II. 429; W. Lindgren, Bull. G. S. A., 1893, IV. 257–298.

differential elevation in the uplifting of the Coast range and Klamath mountains, just north of the fortieth parallel, to the extent of over 2,000 feet." *

A slope of small angular value, viz. 0° 8′ 5″, across the State of Massachusetts carries the southern New England peneplain to an elevation of twenty-five hundred feet in a distance of one hundred and sixty miles. As one stands upon the peneplain in the western part of Massachusetts, he may look to the southeast across an almost even surface of denudation with here and there a monadnock rising above it, a monument of resistant rock.

Warping: New Brunswick, N. J. — The definition of a warped surface here adopted is that given in geometry, namely, a surface generated by a straight line moving so that no two of its consecutive positions shall be in the same plane. Various cases under warping may occur, the marked characteristic of them all being the variability of the criteria.

In the depression or uplifting of the Schooley peneplain † there appears to have been a warp, which causes the portion of the Cretaceous peneplain near New Brunswick to be lower than the rest.

Santa Catalina Depression. — Professor Andrew C. Lawson has described ‡ a very beautiful instance of differential movement between San Pedro hill on the mainland and San Clemente island. Upon the southern California coast and also upon San Clemente are many well marked sea-cliffs rising one above another to an elevation of some 1500 feet.§ These show pauses in a progressive series of uplifts. But between San Clemente island and San Pedro hill lies Santa Catalina island (C. S., 5100), whose land sculpture shows subsidence and not elevation. Upon this island (C. S., 5128, old number 613) there is a good example of a divide almost submerged. Professor Lawson says that the sea-cliffs show more rapid recession than is usually found in stationary or rising coasts. He considers this Santa Catalina depression an orogenic, or local movement, which occurred at the same time or later than the epeirogenic or general uplift, shown by many observations along the coast of California.

Crumpling and Faulting. — Cycles and epicycles caused by uplift or depression merge through tilting, crumpling, and faulting into those inaugurated by mountain-building. A graded series of forms may be con-

* Jour. of Geol., 1894, II. 45.

† Messrs. Davis and Wood, Proc. B. Soc. Nat. Hist., 1889, XXIV. 380.

‡ Bull. Dept. Geol., Univ. of Cal., No. 4, 1893, I. 122–189.

§ See p. 164 and Figure 4.

ceived, and largely filled in with examples, beginning with the area uniformly uplifted and ending with a highly complicated mountainous region. This interesting subject falls outside the province of this paper.

PART II. SEQUENTIAL FORMS.

5. Sea Attack and Transportation.

Differential Abrasion. — Varying hardness of rock is an important factor in subaerial degradation, and it must also have considerable to do with the attack of the sea upon coasts. The two ways of formation of plains discordant with the rock structure have been contrasted thus: "A subaerial baselevel plain is gradually completed by the action of ordinary forces on all parts of its surface," while "a submarine platform is essentially completed strip by strip, once for all, as far as it goes." * Professor Shaler has recently called the monadnocks, the residual masses of harder rock rising above the New England upland, "the most enduring evidences of marine action." †

Without entering into the discussion whether the New England monadnocks were formed by subaerial or submarine denudation, it is the purpose of the writer to use these contrasting interpretations of the same phenomenon as an introduction to the discussion of the effect of relatively hard and soft rock upon marine denudation. Waves will attack softer rock more rapidly than its more resistant neighbor. A promontory of hard rock may thus be formed where the less resistant rock on either side has been eroded by the sea. The ocean, however, tends to convert irregular to straight or gently swinging coasts.

If the land therefore remains at the same level there will come a time when the increased cutting upon the exposed promontory will equal the lessened wearing of the softer material in the re-entrants on either side. After such equilibrium is reached the shoreline will march inward, practically strip by strip. If, on the other hand, there is a gradual sinking of the land, decided inequalities of surface due to differential marine erosion may be covered by the offshore deposits. This has been pointed out both by Professor Shaler and by Professor Davis in the papers quoted above.

Monadnocks versus Marine Remnants. — A distinction should be sought

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* Messrs. Davis and Wood, Proc. B. Soc. Nat. Hist., 1889, XXIV. 375.

† Bull. G. S. A., 1895, VI. 149.

between the remnants above a submarine platform and the monadnocks rising above a subaerially carved peneplain. The burying by slow submergence would tend to protect from decay the sea cliffs and benches, so that when re-elevated and divested of their sedimentary protection, the marks of sea action would show marine origin, at least in part. A depressed peneplain with its monadnocks would also show cliffs and benches, if it remained in its descent at one level for a time sufficient for cutting. Features of shore development must not then be considered as distinguishing between monadnocks and marine remnants.

The vital question is how far the cover extended inland, and what point the former shoreline reached. Inside this limit all differential erosion remnants will have been formed entirely by subaerial degradation, while on the seaward side of the line the sea will have had more or less to do with their formation. After the form of the old shoreline has disappeared, and the coastal plain sediments been more or less completely stripped off, the evidence for the former greater inland extension of the cover will lie in the arrangement of the streams. The area formerly covered will show superposed streams and less perfect adjustment of rivers to structure than is found beyond the limits of the former shoreline.*

Coastal Inequalities. — Many writers have ascribed all inequalities of the coast to differential erosion of the sea. Even as late as 1882, Prof. A. H. Green implies that all bays and other coastal inequalities are due to "the hardness and structure of the rocks." † The tendency in America of later years has been to ascribe all inequalities of the shoreline to the drowning of subaerially carved forms. While submerged topography will account for the greater part of such irregularities, we must not entirely leave out of the consideration the action of the sea.

The agents of the sea are the waves,‡ tides, and currents. Writers differ widely in what they attribute to each of these three agents, and a discriminating study of the work of the three should be made by some careful observer. The present writer is inclined to attribute the attack of the sea largely to the waves, and its transporting action largely to the tides and currents.

* See Messrs. Davis and Wood, Proc. B. Soc. Nat. Hist., 1889, XXIV. 399-410; Professor Davis, Lond. Geog. Jour., 1895, V. 128-138.

† Physical Geology, 577.

‡ For the method of wave attack see Gilbert, Mon. I., U. S. G. S., Chap. II., with references; Lyell, Principles of Geology, 11th ed., 1872, I., Chaps. XX.-XXII.; LeConte, Elements of Geology, 2d ed., 1882, 31-43; Penck, Morphologie der Erdoberfläche, II. 460-497, with references.

Wave-cut Islands. — On the Marblehead coast of Massachusetts we see the more rapid erosion of the trap dikes which intersect the more resistant granite.

Sir Charles Lyell has given instances of differential marine erosion in the drongs of the Shetland islands.* The granite and other harder rocks longer resist the waves than the schists. The many veins of porphyry in Hillswick Ness, Lyell shows, will also in time similarly be etched.

The Orkneys and Shetlands are exposed to violent sea action, and since the shore evolution is here considerably below grade, this is the place where differential abrasion might be expected. The best maps of these islands † show many outlying islets, high stacks, and low skerries, many of which are probably due to abrasion of the sea since the drowning of this region.

Wave-cut islands are typically seen along the west coast of Ireland. Probable occurrences are in the following areas (Ireland, 9, 51, 83, 98, 103, 160, 171, 204).

In the Southern rapids of Peril straits, Alaska (C. S., 8259), the sea is now actively eroding. The current, according to the Coast Survey, is often running ten knots an hour, and the tides between Pinta head and Eureka ledge run with terrific velocity. All the conditions are here favorable for the production of wave-cut islands, and an examination of the charts shows many islands, rocks, and ledges entirely isolated from each other. The sea has here made no attempt to simplify the irregular shoreline by connecting bars.

"Approached by sea, the Aleutian islands seem gloomy and inhospitable. . . . An angry surf vibrates to and fro amid outstanding pinnacles." ‡

Off cape Tschipnuski, Kamchatka, numerous rocky islets, stacks, and skerries are seen upon the map, and in the sketch of Lieutenant Rogers (H. O., 54).

At Blanca and Concon points (H. O., 1232), and at Guacache, Cobija, and Guasilla points (H. O., 1181) on the coast of Chile.

Algodonales point, west of Tocopilla, Chile (H. O., 1265).

Submarine Platform. — The late old-age of shore development, where the land has stood approximately at the same elevation for a period of time sufficiently long for the sea to have carried out its intention, is the submarine platform, the plain of marine denudation. This plain will not lie as far below the surface of the sea as it did in its maturity. The broader expanse of the submarine platform beneath the ocean will prevent the sea from so actively attacking the coast. From birth to maturity the sea pushes its zone of maximum action farther and farther inland, while from maturity to old-age the atmospheric agencies will supply more waste than the shore currents can take care of, and the offshore depth will gradually decrease, though the shoreline will move landward at a lessening rate. The steep cliffs of maturity will diminish in height as old-age comes

* See figures, Principles of Geology, 11th ed., 510, 511.

† Roy. Scot. Geog. Soc., Atlas of Scotland, Edinburgh, 1895, sections XLII, XLIII, XLIV, XLV.

‡ W. H. Dall, Sci., 1896, III. 44.

on, and at a late stage will show as little elevation as was seen in the youthful nip.

While the sea has produced the submarine platform, the land has been worn down by subaerial degradation to a peneplain.* The controlling plain for the production of the peneplain surface is baselevel, "the level of the sea . . . below which the dry lands cannot be eroded." † The surface will never reach baselevel, but will approach it, "in an infinite series of approximations like the approach of an hyperbola to tangency with its asymptote." ‡ A possible qualification of the above statement may be, that where the surface is near baselevel, the wind may excavate a portion down to or even below sealevel.

American and English Views. § — Major Powell, Major Dutton, Mr. Gilbert, and other geologists who worked upon our western interior region, saw the great importance of sea-level as the controlling baselevel down toward which the land is worn. The action of the sea did not enter into their considerations to any extent. The English geologists on the other hand saw upon their island the great destruction wrought by the waves, and the lower level of wave action was their most important plane of reference. Professor Ramsay included the subaerial forces as aids in marine denudation, while later Dr. Geikie ‖ made sea cutting of less importance than subaerial denudation in the production of the plain of marine denudation.

FIGURE 5. SL = sea level. WB = wave-base. P = peneplain. SP = submarine platform. CD = continental delta.

Wave-Base. — The two planes of control should be distinguished, and the almost plains produced by subaerial and submarine degradation be given separate names. Figure 5 shows the relation of the peneplain surface with its controlling baselevel to the submarine platform and its

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* W. M. Davis, A. J. of S., 1889, XXXVII. 480.

† J. W. Powell, Exploration Colorado River of the West, 1875, 208.

‡ C. E. Dutton, Tertiary History of the Grand Cañon District, Mon. II., U. S. G. S., 1882, 76.

§ Since the following section was written, Professor Davis has made a more extensive comparison of the American and English schools; Bull. G. S. A., 1896, VII. 377–398.

‖ Scenery of Scotland, 1887, 137.

controlling wave-base. The term wave-base is here introduced as a comparable term to river baselevel or hard stratum baselevel. It is another local baselevel, which ought to be distinguished from the grand baselevel of the sea.

Thus, at a late stage of development, the peneplain and the submarine platform almost merge into each other; indeed, so much do the forms resemble each other, that the one process or the other has been given by many writers as explaining the total degradation toward a plain. The plain of marine denudation, perhaps better called the submarine platform, is distinguished from the peneplain by its cover of offshore deposits, and the limits of this cover, even after it is partly stripped off, can be found from the arrangement of the drainage.

The need for a separate term for the controlling plane from that of the surface, down to which the forces of degradation are able to reduce the land, is shown when one examines recent writings upon this subject. To speak of the deformation of the baselevel * is like saying a bent cone in conic sections. Both terms imply abstract mathematical surfaces that cannot suffer distortion. The peneplain may be uplifted, tilted, warped, or folded, but not the baselevel. In the same way it is helpful to distinguish between the submarine platform and the wave-base. The offshore erosion surface will approach the depth to which the maximum wave action is possible, but the submarine platform will be cut to that depth only in the zone of maximum wave activity.

Sea Transportation. — When the supply of waste has increased beyond the power of the various currents to immediately deposit it offshore, transportation alongshore will become more important, and aggradation may take place in certain places. The tendency of shore currents is undoubtedly to form curves in the shoreline which will be satisfactory to the particular current acting.

The writer makes the following distinction between the sea action upon the inner shoreline, which includes the more protected coasts of bays, drowned valleys, sounds, channels, etc., and its action upon the outer † shoreline, which is that of the exposed coasts of the ocean. The ocean currents have little direct effect upon the inner shoreline, and the wind has not opportunity to develop, by the formation of waves, current eddies of large radius of curvature upon inland waters. In these narrow arms of the sea the tidal currents are the preponderating force, for here

* Diller, 14th Ann. Rep. U. S. G. S., 1892–93, Part II., 406; Jour. of Geol., 1894, II. 45.

† See Penck, *loc. cit.*, II. 551.

the ocean current and the local wind current do not have a chance to be relatively so effective. It may be stated as a general principle that the most effective agent of shore development upon the inner shoreline of drowned topography is the tidal current. Broad bays form a middle ground where any of the three forces may be the strongest. Upon the outer shoreline the ocean eddy currents are the most effective, while upon lakes and inland tideless seas the local wind currents are the most important factor. The movement of the land waste is in all three cases due largely to the action of the waves.

Offset; Overlap; Stream Deflection. Figures 6, 7, 8. — The three criteria of form by which the dominant current alongshore may be inferred are offset, overlap, and stream deflection. The three usually occur together, but each is found alone.

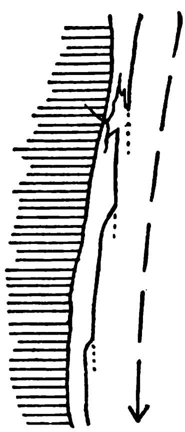

FIGURE 6. Offsets.

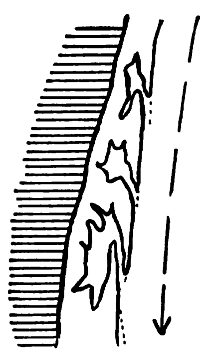

FIGURE 7. Overlaps.

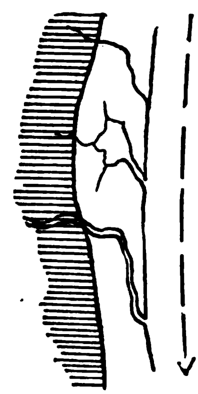

FIGURE 8. Stream deflection.

Types of offset without accompanying overlap are given in Figure 6. Overlaps are commonly accompanied by offsets of the shore curves in the same direction, as is markedly the case in Fire Island inlet, Long island (C. S., 119). One shore curve offsets another when the curve itself or the continuation of the same passes to seaward of the next succeeding shore curve. When this offset is slight, it may be perceived by looking along the shore curve, putting the eye close to the map.

The typical example of offset without overlap is on the west coast of Jutland (Denm., Thisted), where the currents are known to be from the

south, which is in this case the right.* The right shore curve systematically offsets the left along all the western coast of Denmark.

Many examples of similar offsets are known along the coasts of the world, and wherever the dominant current is known from observation the offsets follow this law: THE CURRENT FLOWS FROM THE OUTER CURVE TOWARD THE INNER ONE. On account of the number of cases in which the offsets agree with the observed currents, it is pretty safe to conclude when offsets occur systematically in one direction that the dominant movement alongshore is in all probability from the curves which offset toward those which are offset.

Figure 7 shows typical overlaps. The right hand curve of the outer shoreline laps over the next succeeding curve of the outer shoreline. A curve which overlaps the succeeding one generally offsets it as well, though in places, as is shown in the lowest example in Figure 7, the up-current curve may intersect the down-current one if extended far enough. This occurs where the factors of alongshore transportation are probably changing, and the down-current curve is really made up of two curves, and the up-current curve offsets the down-current one in each case.

The overlap is an intermediate form between the offset and the deflected stream. A graded series of examples might be given from simple offset through various combinations of overlap to a case of stream deflection without any offset.

Along coasts which are formed of unconsolidated materials, it is frequently observed that rivers, brooks, or tidal channels aim toward the sea for a certain distance and then turn and run along nearly parallel to the shoreline, and finally empty to the right or the left of the point which would have been their direct course to the sea. The river's intention to reach the sea as quickly as possible is evidently not carried out where such deflection is seen. Some disturbing force has come in. There seems little doubt that this force is the current alongshore, which has turned the outlet of the stream. Such has been the explanation of many authors.† Figure 8 shows the relation of current to deflection of streams.

Dominant Current. — There is probably wave movement in both directions along the shore at different times, and the form shows in which

* H. Möhn, The North Ocean, Norwegian North Atlantic Expedition, 1876–78, 2, XVIII. 168, Plate XLIII.

† De la Beche, Geological Notes, 1880, II. 11, Plate I. Fig. 8; Reclus, La Terre, 1870, I. 447; Sir A. Geikie, Textbook, 3d ed., 399.

direction the dominant movement has taken place. The dominant movement may not always correspond to the prevailing movement alongshore. A few severe storms causing a strong current from the right during one month might determine forms, which a weak current from the left prevailing for eleven months of the year would not be able to efface.

Figure 9. Typical Current Cuspate Foreland.

Current Cuspate Forelands: Type, Figure 9.* — In adolescence, when the currents have more load than they can carry, it is deposited in forelands of various forms. A characteristic one is the cuspate, of which a typical drawing is given. In it are combined those features of the three Carolina capes † and cape Canaveral (Figure 10) which the author deems important to show the method of growth. Former positions of the shorelines are indicated by the ridges of dunes built by the wind along the shore.

Such former positions are beautifully indicated in Canaveral (C. S., 160, 161), where three or four successive positions of the outline of the cusp, each farther to the left than the preceding, are delineated, besides many lines of aggradation in each position (Fig. 10). Similar lines of growth are seen at cape Fear, where the present right shoreline cuts off the eastern ends of the four dune ridges extending east-southeast from the lighthouse and curving sympathetically with the left shoreline.

Cape San Blas, on the west coast of Florida (C. S., 183, 184), shows four stages on the right side and nine successive stages of aggradation on the left side.

A more striking example of aggradation lines is seen in the cusp of Dars cape in the Baltic (Germ., 61, 62, 63), where thirty-eight systematic and successive shorelines are indicated by dune ridges (Fig. 11). The dominant current is from the right, according to the offsets and hook at the point of the cusp; but the thirty-eight successive shorelines suggest a gradual aggradation of strips, and a change from an earlier condition when the current was from the left. The tidal flats, east of Zingst, point to present transportation and growth toward the left.

* For fuller account see Bull. G. S. A., 1896, VII. 399–411; also see references for papers by Abbe and Tarr.

† See p. 242.

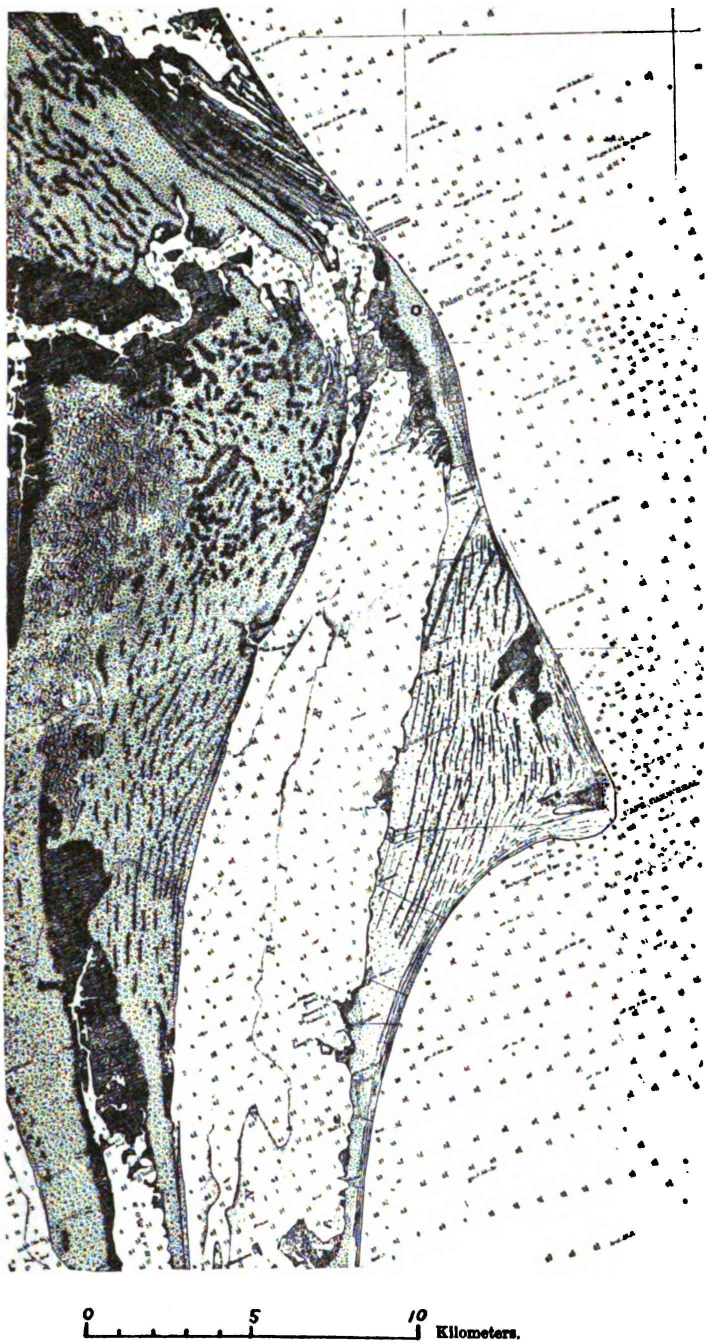

Figure 10. Canaveral Foreland, Florida. (Sheet 161, U. S. C. G. S.)

The topography and geology both imply that this offshore bar is built up of several islands tied together. A very pretty problem for field study is here presented.

A rounded cusp projects into the Baltic north of Wismar bay (Germ., 85).

Markelsdorfer Huk on the northern end of Fehmarn island is a foreland of apparently this same general type of formation (Germ., 40).

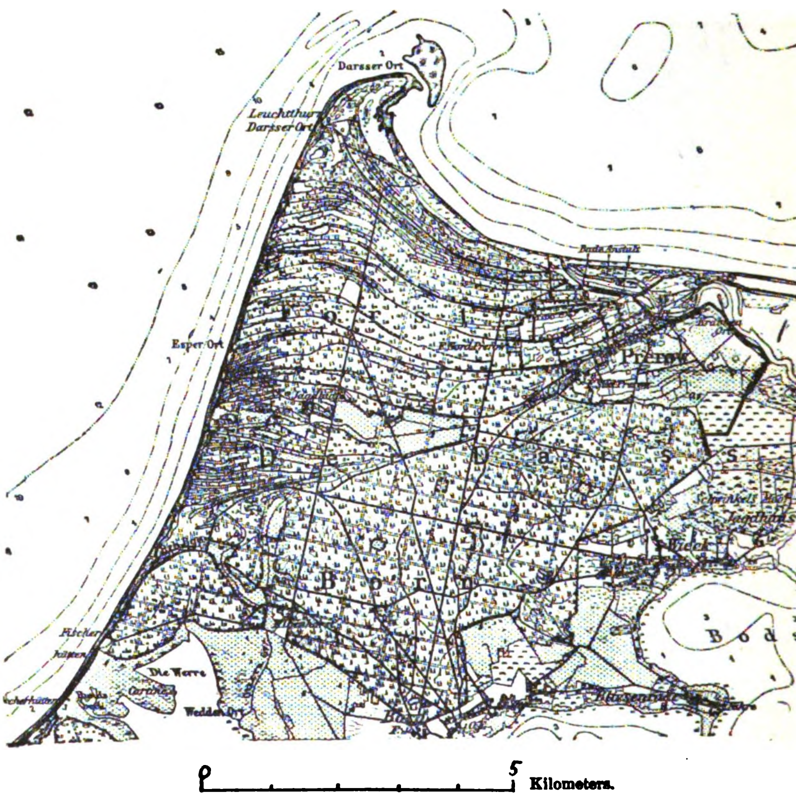

FIGURE 11. Dars Foreland, Germany.

Jaederens point on the Norwegian coast (Nor., 6, B) probably owes its projection in part to current aggradation.

The point del Faro on the northeast of Sicily shows action of tidal currents combined with the large eddy of the Tyrrhene sea. The cusp does not grow at right angles to the direction of the currents through the straits of Messina, but lies between the Messina current and the Tyrrhene current (Ital. and Sicily, 254).

North of Sousse there are two solid cuspate forelands, covered with dunes, which are apparently built by a progressive series of additions to the coast (Tunis, 57).

In small water bodies, lakes and seas nearly without tides, the winds would cause waves which in turn would originate currents of smaller radius of curvature, which should produce smaller cuspate forelands. The cuspate points in the Danish waters are probably such forelands. These are seen on the topographic maps of Denmark in the following localities: Roskilde fjord (Denm., Hilderöd), Söen Mellem Smalandene (Denm., Saxkjöbing, Vordingborg), Limfjorden (Denm., Lögstör), on Langeland and the islands to the west (Denm., Svendborg, Nakskav, Gulstav, Faaborg), and in other localities along the Danish and German coasts.

The Bonneville cuspate forelands are proportional to the currents which existed on the old lake and are similar in size and outline to the Danish cusps. Professor Russell also reports V-bars upon the fossil shores of lake Lahontan.* These cusps seem to have been built upward as the waters of the lakes rose, but the water level never remained constant long enough for the lagoons to have become filled, forming solid forelands, since Mr. Gilbert reports only a partial silting up.†

6. Offshore Bar.

Shelving Shore. — When the sea takes a new position of attack after elevation, if the shore is shelving, wave-base intersects the smooth bottom at some distance from the simple new shoreline, and the point of maximum wave abrasion is out from the coast at some point on the shelving shore. This condition would obtain in the ideal case assumed in Part I. From the forms of observed shores which slope gently beneath the water, the action of the sea appears to be somewhat as follows. The waves at first beat upon the coast and cut a faint cliff or *nip*. The point of maximum wave action is offshore, and there the waves heap up sand from the bottom and a bar is formed alongshore. The waves abrade rapidly until the offshore bottom to seaward of the bar approaches wave-base. During this deepening the waves have broken farther and farther offshore, so that the bar has gradually moved seaward. When now the bottom to seaward of the bar has been abraded almost to wave-base, a condition of shore-grade is reached: the sea is able to transport and build into the continental delta whatever waste is supplied from the bottom and offshore bar. As soon as material is taken from the bar it will retreat toward the land.

Stages. — The period of upbuilding and seaward growth of the offshore bar has been regarded as the youth of the shoreline, and the period of cutting back as adolescence, since the latter is a graded condition. During youth the seaward growth of the bar leaves long marshy strips, or "slashes," between the successive dune ridges formed along the shoreline. These become overgrown with bushes, peat, etc. The lagoon behind the

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* Mon. XI., U. S. G. S., 93.

† Lake Bonneville, 121, Pl. XVIII.

bar also is frequently converted into marsh. In the landward retreat of the shoreline, this vegetable layer is discovered at or beneath sealevel, covered by the beach sands, as on the New Jersey coast.

When the offshore bar has been completely cut back, the nip has been extinguished, and the sea is actively cutting into the coastal plain, leaving a more or less pronounced sea cliff, maturity is reached.

No Offshore Bar. — When the initial slope of the coastal plain is so steep that the sea is able to begin the production of the submarine platform immediately offshore, shore-grade is quickly attained, youth and adolescence are of short duration, and the coast reaches a mature stage of development without the production of an offshore bar. This has probably been the case in eastern Italy (page 186).

Youth: Texas. — The offshore bars on the Texas coast are very marked features in that elevated region (C. S., 205, 206, 207, 208, 209, 210, 211, 212). An apparent earlier position of the bar is shown by the string of small islands inside the present offshore bar. The sea is here building apparently from the bottom in great measure. The transportation alongshore as indicated by many offsets, Cavallo pass, Galveston entrance, etc., is dominantly from the left, caused doubtless by the eddy circulation in the gulf of Mexico. There are occasional stream deflections to the left, as Cedar bayou and San Bernard river, which are caused possibly by backset eddies from the main circulation. The littoral forms in this region are complicated by an episode of slight drowning. A great variety of dune forms are shown on this bar.

The map of Costa Rica by Dr. Frantzius* shows a characteristic offshore bar. The scale of the map is too small to show indications in which direction the bar is moving, so this may be an adolescent coast.

The eastern coast of Corsica (Fr., 261, 263, 265) shows an offshore bar, but whether advancing or retreating, the writer does not know.

Off the Ogunquit-Wells Beach coast there is an offshore bar upon which the writer could find no evidence as to which way it is moving.

The offshore bars on the Atlantic slope are further advanced on the whole than the Texan bars. Youthful bars prevail in Texas, and adolescent ones from North Carolina to Long island. Field study of these bars is needed to bring out more fully the history of the sequential forms. The following quotation shows the meagre character of existing descriptions.

The offshore bar opposite Beaufort harbor, N. C., "is mostly covered with a low pine and mixed growth, and its average width is about half a mile; the sand hills and ridges upon it are from 20 to 35 or 40 feet high." †

Adolescence: Southern New Jersey. — The Geological Survey of New Jersey reports that the sand dunes overlie a layer of black soil along the shoreline, at differing heights at different localities. The lagoon along the southern coast of New Jersey is largely converted into marsh, while that along the central portion of

* Pet. Geog. Mitt., 1869, XV. 81, Tom. V.

† H. L. Whiting, U. S. C. G. S., 1851, Appen. 28, 483.

the State is little filled, indicating an earlier stage. In the northern portion of the State the offshore bar merges into the southern wing of the Long Branch behead-land (page 213).

Upon the south side of Long island the sea has devoured the land to an appreciable extent during the historical period. Meadows and cultivated lands have been covered with sand, wagon tracks in peat have been found on the ocean side of the dunes, while peat, cedar stumps, and tangled roots occur to-day between the sand hills and the sea. These traces of land life seaward of the dunes indicate a march of the dunes landward,* and a general pushing of the offshore bar inland.

7. Dissected Coastal Plain.

Surface Form. — On page 155 it was shown that the stage of development of the surface of a coastal plain may not be the same as that of the coastline of the same region. This subject comes more properly under the cycles of development of land forms; but, since the coastal plain is one of the main criteria of uplift, the sequential forms will be briefly sketched.

Mr. W. Lindgren shows a characteristic section of a Quaternary coastal plain lying on a granite oldland,† but he does not use its stage of dissection to show the time since the elevation of the region around San Diego.

Youthful Dissection: Ogunquit, Maine. — In southern Maine the forms indicate that there has been a recent episode of uplift revealing a narrow coastal plain, which fills in the irregularities of the coast made by a previous depression. The streams have only begun to intrench themselves upon this late deposit.

The Monopoli coastal plain on the "heel" of the Italian boot shows youthful dissection of a marine plain (Ital., 190, 191). The Pliocene strata ‡ present a surface gently rising from the sealevel to heights of from 100 to 200 meters at the foot of an abrupt slope of Jurassic and Cretaceous rock. This slope rises from 75 to 250 meters above the plain, and has the form of an elevated former sea cliff now slightly dissected. A problem for field study is the cause of the minutely ragged outline of the present shoreline.§ There is no offshore bar shown with this coastal plain, which may be accounted for by the fact that the slope of the surface of the coastal plain is considerable, 100 meters in 5 kilometers, and therefore it is probably steep enough for the direct attack of the sea. The coastal plain character of the heel of Italy is well shown on the topographic sheets by the radial arrangement of roads (Ital., 202, 203, 204, 213, 214, 215, 223). The towns are like the hubs of wheels, the spokes of which are the highways. The distribution of infaces, streams, and outcrops suggests that the area has been developed in several cycles, a study of which in the field would be most attractive.

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* A. G. Pendleton, U. S. C. G. S., 1850, Appen. 8, 80, 81.

† Proc. Cal. Acad. Sci., 1888, L., Pl. III.

‡ Carta Geologica d' Italia, 1 : 1,000,000, Roma, 1889.

§ See page 239.

The Pyrgos coastal plain on the western end of the Peloponnesus shows characteristic intrenching consequent streams.*

The Sykonia coastal plain, south of the gulf of Corinth, is much complicated by faults.† The streams are frequently lost in crossing the gravel of the youngest step.

Adolescent dissection: Eastern Italy. — Eastern Italy, north of the "spur," from Pesaro to Termoli, is a coastal plain of Pliocene strata ‡ dissected by consequent streams now aggrading (Ital., 140, 141, 147, 148, 156). There is indication of captures, particularly in the Pescara, Saline, Vomano, and Sangro rivers, but study upon the ground is needed for proof. Several streams show cutting of the right bank more than the left, Biferno, Fortore, Sangro, Pescara, and Tavo.

Many portions of the Atlantic and Gulf plains of the United States, and of the North German plain show characteristic adolescent dissection.

Mature Dissection: Eastern Virginia. — The form of the surface of the dissected Neocene strata east of Richmond, Virginia, indicates mature dissection. The slight drowning of the streams indicates that since dissection there has been an episode of depression.

A portion of the coastal plain of southern Sicily where there is the least deformation shows quite typical mature dissection (Ital. and Sicily, 272).

Adjustment of Drainage. — A characteristic feature of maturity is the adjustment of streams according to the structure of the region. The most perfect mature adjustment will result from (1) considerable diversity in the size of the initial consequent streams; (2) considerable altitude of the land-mass; (3) considerable diversity of resistance in the strata that are cut through by the streams; and (4) a significant amount of inclination in the strata. § Two successive cycles of uplift will give more complete adjustment than a single cycle.

8. Fading Elevated Shoreline.

Lake Shorelines. — Although some of the finest known examples of initial elevated former shorelines occur upon shores abandoned by lake waters, nevertheless these forms as seen to-day have entered their sequential stages and are fading away. This fact has not been forced upon the reader's attention in the articles upon lake shorelines, and he is left to infer that an elevated former shoreline remains as it was left by the retreating water. Of course the shoreline of a lake, whose water has

* Dr. A. Philippson, Der Peloponnes; topographical and geological charts, sheet I. section IV.; text, 321–323.

† *Loc. cit.*, sheet II. 118, 153; also see Der Isthmos von Korinth, Z. d. G. f. E., 1890, XXV. 1–98.

‡ Carta Geologica d' Italia, 1 : 1,000,000, Roma, 1889.

§ W. M. Davis, Lond. Geog. Jour., 1895, V. 133, 134.

abandoned its former stand on account of the removal of its barrier or down-cutting of its outlet, is in the topographic sense as truly an elevated former shoreline as if the land had been raised. The relative position of land and water is changed.

Typical forms of Bonneville. — Many of the illustrations of shore forms of the Bonneville, Provo, and levels intermediate in position between lake Bonneville and Great Salt lake serve as types of elevated former shorelines, in youthful stages. The deltas, terraces, embankments, cliffs, V–bars, bay-bars, and the tying of islands to the mainland are all characteristically shown. The stratigraphic and paleontologic proof of the relative age of the shorelines is brought out by Mr. Gilbert, but the fading features of the older shorelines are not dwelt upon to show relative ages.

Lake Agassiz. — The descriptions of the shore forms of the ice-dammed glacial lake Agassiz are given in this same manner, as if the forms were formed once for all and would forever remain as constructed. Gen. G. K. Warren set aside the hypothesis of an ice-barrier and argued for an actual change of level, depression to the south accompanied by a rise to the north. Mr. Upham has traced the various beaches formed by the different water levels and shown them to have been the result of an ice mass to the north gradually retreating toward Hudson bay. These elevated former shorelines rise from south to north and from west to east, in the direction of the former ice-fields, the amount of slope varying from zero to one and one third foot per mile. Since these old shores must have been horizontal when formed, their present position shows a tilting since the time of lake Agassiz.

Marine and Lake Terraces. — Early writers used the beach form to show elevation,* but they often did not distinguish between the seashore forms and those which had been produced by water above the sealevel. One of the most fruitful sources of error has been in regarding the terraces of ice-dammed lakes as produced by marine action. The classical example is that of the Lochaber terraces, the Parallel Roads of Glen Roy. For an historical discussion of the change of view from the detrital dammed lake to the action of the sea and finally to the present hypothesis of an ice-dammed lake, see "The Great Ice Age," by Professor Geikie. † The geographic criteria for the differentiation of the similar forms produced by these two processes are these. At the level of the

* R. Chambers, 1847, and many later writers.

† 3d ed., 1895, 282–285.

supposed ice-dammed lake the terraces will be approximately continuous except where the ice stood. On the drift barrier hypothesis it was very difficult to explain how the terraces remained while the barrier was removed, but the ice-barrier would disappear by simple melting, and therefore the terraces would remain in nearly their initial form after the retreat of the ice and removal of the water. The upper terrace level would correspond in elevation with the height of the col over which the lake discharged. This relation to the col has been worked out in considerable detail in the study of the Great Lakes.* A reliable geologic criterion is the occurrence of marine shells, which are found in marine beaches but not in ice-dammed lake terraces.

Examples. Raised beaches are found in Ireland on the north coast, in Killary harbor, along Kenmare and Glengarriff bays, and elsewhere, according to Mr. Hull.†

For the raised beaches of Great Britain reference will be made to the papers by the following authors: Ansted, Chambers, De la Beche, A. Geikie, J. Geikie, Godwin-Austin, Prestwick, Richardson, Trevelyan.

The literature on Scandinavian ‡ raised beaches is extensive, and there are many fine examples of fading elevated shorelines upon that coast. The features do not show distinctly enough upon the topographic maps for purposes of illustration.

Old beaches at various levels above the water of Pechora bay in the Great Tundra region of northern Russia appear to be former shorelines. § Mr. Jackson does not mention less perfect terrace forms the further he went from the present shoreline, but he proved the progressive stages of uplift by the less perfect preservation on the more elevated beaches of the pine tree trunks, which he considers as brought down by the Pechora river.

There is a former shoreline near Ogunquit, Maine, and also farther to the northeast, upon which little work has been done since uplift.

There is an 800 foot cliff six miles east of San Roque point, Lower California, which should be examined in the field to determine whether it is a former sea cliff or not (H. O., 1268).

Another case suggestive of uplift is seen in Santa Rosalia bay, Lower California (H. O., 1100, 1193). The lack of more accurate information about this region makes it impossible to use it as surely showing uplift.

Cliffs 75 feet high are seen along the Sonora coast, Mexico, near the mouth of the Colorado river. They are so distinct as to indicate a recent elevation (H. O., 800).

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* See papers by Fairchild, Gilbert, Lawson, Leverett, Newberry, Schott, Spencer, Taylor, Upham, and Warren.

† Physical Geology and Geography of Ireland, 1878, 107; see also paper by Kinahan.

‡ See pp. 158–160.

§ F. G. Jackson, The Great Frozen Land, Macmillan & Co., 1895, 129, 262. Map.

Superposed Drainage. — No attempt has been made in this study to work out the sequential stages in the fading of elevated shorelines. This problem is intimately connected with the dissection of the land, and depends largely upon the factors which control such dissection in any given locality. The shore deposits being coarser would probably remain longer than those finer materials laid further out from the old shore. When however all the shore deposits themselves are eroded away, the amount of the former coastal plain overlap may frequently be inferred from the arrangement of the streams. Where there never had been a cover, the adjustment of the drainage to the structure would be more perfect than where the streams had taken consequent courses over an uplifted coastal plain. The coastal plain sediments would overlie uncomformably whatever structures happened to occur in the offshore region of the previous cycle, and thus the streams in cutting through the cover would have many chances to become superposed upon unexpected difficulties beneath.* The line between the region of well adjusted drainage and the region in which superposition of streams is found represents a former shoreline, now elevated and in a late sequential stage.

9. Islands.

Consumption by the Sea. — As a part of the sea's work to reduce all the land to a submarine platform just above wave-base, the islands formed by the depression of a region are some of the first forms to be demolished. Very small islets are quickly reduced to skerries and to submarine reefs. Large islands are more continental in character, and their coasts may become mature long before the islands themselves are consumed. These larger islands are not as a rule tied to the mainland by bars. But islands, which range in size from an area of one third of a square mile up to some two hundred square miles, are very frequently tied to the mainland by bars in the process of their demolition by the sea.

Upon the coast of Italy where island-tying in its various stages is beautifully shown, such a bar is called a tombolo.† For convenience in distinguishing island-tying bars from those of other kinds, the writer proposes to call every bar of this kind a *tombolo,* giving an English plural tombolos.

Loop-bar: Shapka, Figure 12. — An island at some distance from the mainland may be so large that the sea cannot dispose of all the detritus

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* See fuller statement by Professor Davis, Lond. Geog. Jour., 1895, V. 128–138.

† See Figure 16.

worn from the island, and then in youth this waste tails off on right and left toward the mainland or in the direction of the quietest water. If the island is so far from the mainland that these spits cannot reach land, they are most likely, in swinging back and forth with varying currents, to join each other and thus form a loop-bar.

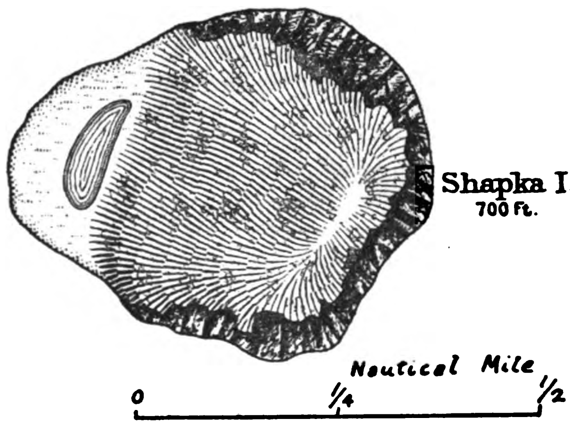

FIGURE 12. Loop-bar: Shapka Island, Alaska.

The form of Shapka island, Alaska (Figure 12), indicates that it had two spits formed on its lee side from the waste of the eastern cliff face, and that these two have now joined, forming a looped bar enclosing a lagoon (C. S., 8881).

Cup butte, Utah, is an example in the fossil condition.*

San Juan Nepomezino island, Lower California, has a salt lagoon at its southern end evidently similarly inclosed (H. O., 42).

Cockenoes island has two long stringing bars pointing toward the coast at Norwalk, Conn., but the bars have not as yet joined (C. S., 116, 8039).

Endelave island (Denm., Bogense) is being consumed on the east and south sides and the material is transported around the north and west ends. This is shown by the hooked spit on the west end and by the five lines of slashes, or narrow lagoons, inclosed by successive outgrowing beaches. If this process is continued a little farther we shall here see another Shapka island with enclosed lagoon.

Flying-bar: Sable Island. — When an island is completely reduced to a submarine condition, the bar formed from its waste may still remain. A case like Shapka, when the former island was completely consumed, would give a flying-bar.

* Gilbert, Lake Bonneville, p. 55, Pl. VI.

Sable Island, composed of unconsolidated materials, is rapidly disappearing.* The map shows an enclosed lagoon, which was formerly nearly twice its present length.† Its form and structure suggest that it represents a flying-bar, after the island, from which its materials were derived, had been completely destroyed.

Simple Cases of Island-tying and their Stages. — One of the features of shore development following depression which shows in most clear and decisive terms the relative time since depression, is the formation of tombolos connecting islands with each other and with the mainland. When the sea is able to do the work given it to perform, shore-grade is established and littoral transportation occurs along the base of the cliffs, which are cut on the more exposed portions of the island and mainland, and deposition begins along the edge of the currents in the comparatively dead water. Such dead water naturally occurs upon the protected side of the island between it and the mainland, and a tombolo is begun usually upon that side. According to the direction of transportation the bar may grow from the island, from the headland, or from them both. The essential point to bear in mind is this: the currents will seek to alter the shoreline better to satisfy their conditions of work.

Numerous examples from various localities are given of the seven stages into which island-tying has been divided. The lists under this and other headings of the present article are however not at all exhaustive, enough examples being given in each case to bring out the successive stages of development and to show the play of the variable elements within the limits of each stage.

I. *Initial Island* (Birth): *Austria; Sweden.* — The first stage in the life of an island is where no work whatever has been done upon it by the sea. Great variety of form and size will occur, depending largely upon internal structure and pre-natal development. The longitudinal structure of Austria, the transverse structure of Casco bay (Figure 1), and the concentric structure shown on the Vaxholm sheet of Sweden, give markedly different island forms. The mature dissection of Scandinavia gives many small islands, while the more youthful dissection in the Puget sound region shows but few islands, and these much larger.

II. *Nipped Island* (Infancy): *Sweden; Maine,* Figure 1. — The sea first attacks the coast and makes a nip all around the island, but cuts more upon the exposed side. The sea at first can dispose of all the waste from the island.

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* Patterson, Trans. Roy. Soc. Can., 1894, XII. (2) 1–50. Map.

† *Loc. cit.*, p. 37.

Many islands along the east coast of Sweden (Swe., 11, 17, 22, 29, 37, 46, 67, 68, 76, 85, 86, etc.); also on the west coast (Swe., 18, 24, 25, 32, etc.).

Maine (C. S., 101, 102, 103, 104, 105, 106).

Numerous examples on the coast of Norway (Nor., 5, B; 48, B; 49, C; etc.).

Many islands among the Orkney, Shetland, and Hebrides on the north and west of Scotland (Scot., 58, 59, 101, 104, etc.).

Off Marseilles (Fr., 247) there are several very young islands.

Lipari islands, Tyrrhene sea (Ital., 244).

Capo Passero island, Sicily (Ital., 277).

Gemini and Corbella, south of Elba (Elba).

Islands west of Fosana, Austria (Austr., 26, IX).

Numerous islands in the Adriatic where ideal possibilities for future tying exist (Austr., 31, XIII, XIV; 34, XVII; etc.).

III. *Uncompleted Tombolo* (Youth). — When more waste is supplied than the sea can deposit offshore, transportation alongshore begins, and there is a tendency to aggrade the surplus load of detritus. Such building would naturally be expected to occur in the comparatively quiet water between the island and the mainland. This is found to have taken place in many localities. According to the several conditions of the variable factors in the problem, the tombolo may begin to grow from the mainland, the island, or from both.

a. *Attached to Mainland only: Gigha.* — The typical example is seen on the west coast of Scotland, where Rhunahaorine point projects as a cuspate foreland from the mainland toward the island of Gigha (Scot., 20). This foreland is of the nature of the tidal forelands described on page 214, and a tombolo may never be completed across the deep channel.

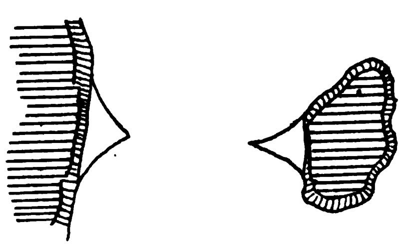

FIGURE 13. Diagram of Uncompleted Tombolo.

A shoal extends from the large island, Berneray, toward the rocky stacks, Sgeir a' Chail (Scot., 89). This islet is fast being consumed by the sea, and probably never will be tied.

Lingay strand extends below high tide level toward Lingay island (Scot., 89).

Callao, the seaport of Lima, Peru, is built on the tombolo growing toward San Lorenzo island (Stieler, 94; Middendorf, Das Küstenland von Peru, 1894, 36).

Angel island in San Francisco bay, California (C. S., 5581).

b. *Attached to Island only: Tunö.* — From Tunö island (Denm., Samsö) there projects toward Samsö island a lanceolate cusp, showing the attempt to tie the smaller to the larger island.

Another cuspate foreland projects from Taransoy island toward Harris island (Scot., 98).

Vigso island has two curved spits not quite able to reach the mainland (Denm., Saxkjöbing).

c. *Attached to Mainland and Island: Aebelö;* Figure 13. — A bar is forming from Aebelö island and from a smaller island close to the mainland (Denm., Bogense).

Another example is Spectacle island in Boston harbor (C. S., 337), where the "nose-piece" of the spectacles consists of two cusps almost joined. Upon the Coast Survey chart these two islands are not joined, but in 1896 the writer saw from a steamer that the tombolo was completed.

Between Pabbay and Berneray islands a tombolo has begun to grow which consists so far of a cuspate projection from each island (Scot., 89).

The tombolo connecting North rocks with the Irish coast (Ireland, 49, 50) is not completed, and it is very probable that these rocks will be completely consumed before tying on is accomplished.

The flats between Barra and Fiaray islands represent the attempt of the sea to tie islands together (Scot., 58, 59, 68, 69). The flats surround three other islands.

Tombolo growth is indicated from both Ibiza and Formentera islands, the advance from each island being made toward the other (Spain, Bol. VII, Lám. B). There are several small islands in the line of probable future growth, which will be surrounded by the completed tombolo.

Marrowstone island, Washington, at present is detached from the peninsula to the west, Kilisu harbor having communication across the bars at both its northern and southern ends (C. S., 6450 and 647).

Several of the islands in Sitka harbor, Alaska, are soon geographically to become land-tied; as, for example, Cannon island, Beardslee islands, and The Twins (C. S., 725).

Isla de Ápies, Mexico (H. O., 878), is now connected at low water.

Rush and Ackerman islands, Costa Rica, are nearly in this stage (H. O. 1028).

Redonda and Siriba islands, Brazil (H. O., 486).

A tombolo largely of mechanical construction though there is some coral growth in it, is attempting to connect Ceylon with the mainland.*

IV. *Completed Tombolo* (Adolescence). — As a rule when islands along a stretch of coast are completely tied to the mainland by tombolos, the coast as a whole is graded, and may be regarded as in adolescence. Occasional youthful features will persist after the region has reached adolescence, and in the same way completed tombolos will sometimes be found where the other features of the coast are indicative of youth. There are three classes of tombolos: single, Y-shaped, and double.

a. *Single Tombolo: Nahant,* Figure 14. — Nahant is tied to the Massachusetts coast at Lynn by a single tombolo, which is typical, with the exception that the island itself is made up of Big and Little Nahant, which are themselves joined by a tombolo.

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* Map by J. Walther, Pet. Geog. Mitt., Erg. 102, 1891.

Many other cases of single tombolos occur in Boston harbor (C. S., 337; G. S., Boston Bay, Mass.). Among these may be mentioned Winthrop head, point Shirley, Peddocks island, Hull, and the islands tied by Nantasket beach.

Little Koniushi island, Alaska (C. S., 8881).

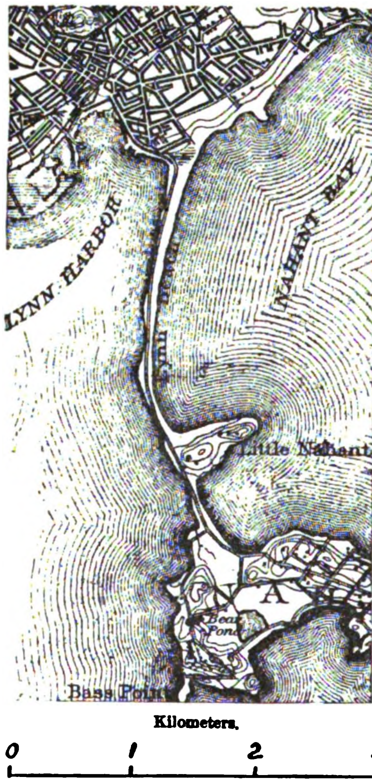

FIGURE 14. Single Tombolo: Nahant, Massachusetts.

Biorka island, Alaska, is made up of two islets tied together by a bar (C. S. 724).

George island, Alaska, shows composite building (C. S., 741).

Amaknak island, Alaska, has three component parts (C. S., 8901).

Morro Ingles island, Paz point, and San Vicente island, Mexico (H. O., 640).

Mare island (C. S., 5524, old number 625) is a case in San Pablo bay where an island has been tied by a tombolo to the mainland.

Spider island, Alert harbor, Chile (H. O., 926).

Mt. Division, 1880 feet high, is connected with the mainland of Peru by a low sandy isthmus (H. O., 1178, 1185, 1162), which is probably a tombolo.

Morro of Barcelona, Venezuela (H. O., 874).

An island off the Bonneville shoreline near George's ranch was tied by a tombolo, in which three attempts at tying are figured by Mr. Gilbert.*

Gilsay island in the sound of Harris (Scot., 89).

Taransoy is apparently built up of three islands tied together (Scot., 98).

Howth peninsula has the form of an island tied to the mainland northeast of Dublin (Ireland, 112). Transportation is indicated both from the cliffs of the mainland toward the island and from the island along the tombolo. Broad tidal flats, cut with runways, occur on the right and left of the tombolo.

Mweenish island is made up of three drumlin-shaped portions connected by narrow necks, presumably tombolos (Ireland, 115).

Illaunatee or Straw island, one of the Aron islands (Ireland, 118).

The Chesil bank † connects the isle of Portland with the mainland of Dorsetshire (Eng., 17).

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* Mon. I., U. S. G. S., 113, Fig. 23.

† For the literature on this tombolo consult De la Beche, Geol. Notes, 1830, II. p. ix; Geikie, Textbook, 3d ed., 1893, 451.

The rock of Gibraltar (Q. J. G. S., XXXIV., 1878, Pl. 23; Brit. Ad., 144, 1448) was an island, and is now tied.

Sermione, Italy, is on an island in Garda lake connected by a bar three kilometers in length, three times the length of the island (Ital., 48).

Cape Milazzo (Ital. and Sicily, 253).

Penisola Magnisi, and that on which Augusta is built (Ital. and Sicily, 274).

Monte Enfola (Elba).

The peninsula southwest of Vari, on which Zoster cape is situated (Attica, VIII).

Koroni (Attica, XI).

Probable tying of islets to Samsö island (Denm., Samsö).

Faejo island is composed of two parts tied with a tombolo (Denm., Saxkjöbing).

Knudshoved point (Denm., Saxkjöbing).

Bogo island has Farö tied to its northwest point by a long tombolo (Denm., Vordingborg).

Avernak island (Denm., Faaborg).

Drejo island is composed of two tied by a narrow tombolo (Denm., Svendborg).

Two or three islands were apparently tied together to form the hook north of Aeröskjöbing (Denm., Svendborg).

b. Y-tombolo: Morro del Puerto Santo, Figure 15. — The type of the Y-tombolo, where one bar from the island unites with two from the mainland, is found in Puerto Santo bay, Venezuela (H. O., 374).

Northeast point on St. Paul island, Alaska (C. S., 8990, old number 886) is connected by a Y-tombolo enclosing a lagoon.

Mahedia, Tunis, is figured by Reclus as tied in this manner.*

Nicolaos (Attica, XVII).

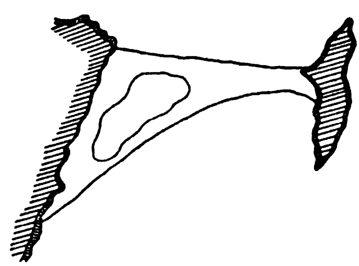

FIGURE 15. Y-tombolo: Morro del Puerto Santo, Venezuela.

c. Double Tombolo.—If the island is comparatively near to the mainland, and if it has considerable extension alongshore, there will generally be formed a tombolo from either end, enclosing a lagoon. Aebelö and Nahant are too far from the coast to have a double tombolo, but Marblehead neck and Monte Argentario (Fig. 16), are near enough and large enough to have a bar at each end.

(1) *Only one Bar completed: Marblehead Neck* (C. S., 335). — Only one bar is here built, and that in recent geographic time, for the shore is not graded outside of the tombolo, either on the right at the southern end of the island, or on the mainland at the left. The tombolo has probably been built largely from the bottom, since both ends form nearly a right angle where they join the island and mainland.

Stony island in lake Ontario, New York, is composed of two islands, probably drumlins, joined by a bar at the southern end, while a second bar is nearly completed at the northern end (G. S., Stony Island).

The island east of Port Townsend, Washington, is joined by one bar at the head of Oak bay (C. S., 6405).

* La Terre.

Bodega head, California (C. S., 630), appears to be an island tied to the mainland by a bar, probably broadened by elevation since it was built and now having its surface much diversified with dunes. A second bar is almost completed, a spit extending from the mainland nearly across Bodega bay. Bodega head like Tomales point to the south is of resistant granite,* east of which the longitudinal valley, now shown by Bodega and Tomales bays, was carved in the weaker sandstones, along a probable fault according to Professor Lawson.

Point Galero, Mexico, is tied by San Juan beach, and a second bar enclosing Chacahua lagoon is being built (H. O. 935).

Copenhagen is apparently built upon a bar connecting Amager with Seeland, and the buildings and fortifications of the city have much altered the former appearance of the bar, harborage being gained by maintaining water communication across the tombolo (Denm., Kjöbenhavn).

Helnes island is joined by a bar at its northern end (Denm., Vissenbjerg). Overlap, offset, and stream deflection all indicate a current from the right, so that the tombolo probably grew from the island to the mainland.

A small island south of Faaborg (Denm., Faaborg).

Several cases along the east shore of the Cattegat (Swe., 18, 24, 32, 41, 51, 61).

Kekenis is tied to the larger island of Alsen and the second tombolo is now beginning as a spit on the other end of the island (Germ., 24; Denm., Faaborg).

An island north of Glücksburg in the Flensburger fjord (Germ., 23).

Halbinsel Wustrow (Germ., 85).

Pulitz is almost tied (Germ., 64).

Several islands are strung together at the southeast point of Rügen island (Germ., 64).

Eye peninsula is apparently tied to Lewis island (Scot., 105), but rocky ledges are shown in the tombolo, and separation may never have been complete.

Vatersay island in the Hebrides is composed of two high portions connected by a lower neck (Scot., 58).

Peninsula point, California (C. S, 5581), is tied by one bar and a second is nearly completed.

Conanicut island (C. S., 353) in Narragansett bay is made up of two portions joined by a bar.

(2) *Both Bars completed: Monte Argentario,* Figure 16.—Monte Argentario, Italy, is an instructive example in explaining the method of tying islands.

In the interior of Orbetello lagoon a bar extends from the mainland toward the island. This tombolo was probably the first built, from the mainland to the point where the village of Orbetello now stands. Meanwhile a bar further north, *Tombolo della Giannella,* was growing from the mouth of the Albegna river toward Monte Argentario. At a little later stage shore-grade was established along the southeast coast of the island and the *Tombolo di Feniglia* grew toward the mainland. The growth of this third tombolo prevented the extension of the Orbetello tombolo.

The reasons for the above interpretation are as follows. The tidal inlet across the Tombolo della Giannella is close to the island while that of the Tombolo di Feniglia is next to the mainland. With such simple bars as these are, where there

* J. D. Whitney, Geol. Sur. Cal., 1865, I. 84, 85.

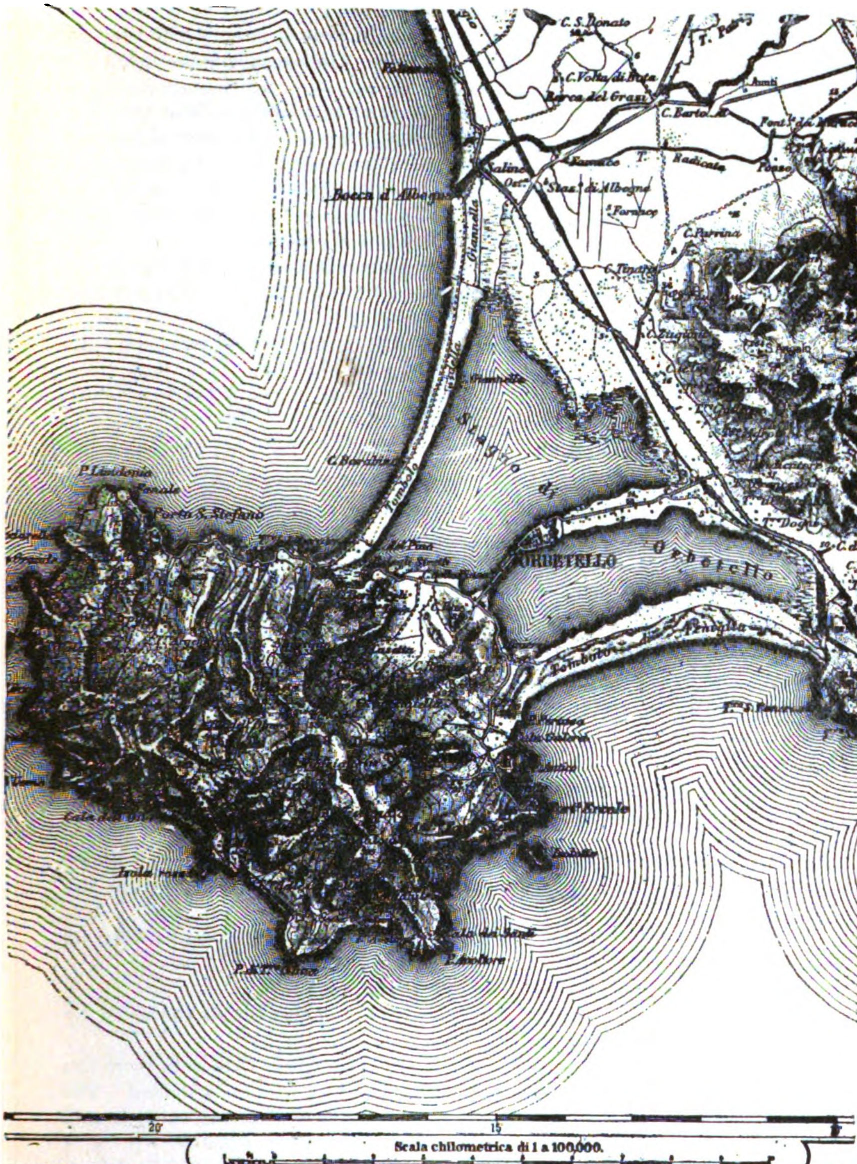

Figure 16. Tombolos: Monte Argentario, Italy.

has evidently been no complete closing of lagoon and then a later reopening, this would indicate the direction of growth, particularly when it accords with the evidence from the shore curves, as it does in this case. This example then apparently combines the features of single and double tombolos.

Monastir (Tunis, 57) is built on an island tied by two tombolos. This example is worthy of special field study to bring out the relations of the several uncompleted tombolos, apparently built from the mainland toward the island before the formation of the present tombolos which enclose the others.

Jasmund is tied to Rügen island by two beautifully curving tombolos (Germ., 42, 64). At Lietzow there is a third connection with the mainland across a narrow portion of the enclosed lagoon, but this in part at least is artificial. Transportation is indicated as slightly stronger from the right, while the squareness of the bar suggests that it was built largely from the bottom.

San Juan Nepomucino island, Lower California, is composed of two parts connected by bars completely enclosing a salt lagoon (H. O., 1228).

Margarita island, off the coast of Venezuela, consists of two individuals joined by two bars enclosing Laguna Grande (H. O., 374).

Presqu'ile de Giens (Fr., 248).

V. *Lagoon-marsh-meadow* (Adolescence): *Colchester Point.* — After formation of a lagoon by a Y-tombolo or a double tombolo, the wind blows in sand from the beaches and streams, and tides deposit silt, so that in time the lagoon is converted into marsh and the marsh in turn into meadow, if the island is not first consumed by the continued attack of the sea.

On the Plattsburg, N. Y., sheet of the Geological Survey, at Colchester point, Vermont, are two cases of filled lagoons, each having an almost extinguished pond. The western pond still maintains connection with the lake, while the eastern pond has no outlet.

The lagoon between Cumberland head and the mainland is two thirds filled, Woodruff pond overflowing across the last built bar into lake Champlain (G. S., Plattsburg, N. Y.).

"The Bonnet" on the west side of Narrangansett bay appears to be an island tied to the mainland (C. S., 353). Wesquage pond is the lagoon between the tombolos.

Sachuest point, east of Newport (C. S., 353, 3044), has the lagoon between its two connecting tombolos almost completely filled.

Monte Circeo south of Rome is completely tied (Ital., 170).

Tiree island (Scot., 42) appears to be composed of two islands connected by "The Reef." Further study is here needed.

Between San Francisquito and Santa Teresa bays, Lower California, there is a low dune-covered tract connecting land 300–600 feet high with the mainland. The only trace of a lagoon is the bed of a pond, half a mile in diameter, which is said to contain fresh water during four months of the year (H. O., 638).

Three islands are tied together and to the mainland west of Sacrificios island, Mexico. Two of the lagoons are completely filled, and the third one is more than half filled (H. O., 875).

The lagoon between the three or four individuals of Santa Maria island, Chile, is completely converted into marsh (H. O., 1209).

Alki point, Washington (C. S., 651; G. S., Seattle). This point may never have been separated from the mainland.

The northern portion of Unalashka island from cape Kalekhta to Constantine bay, Alaska, has been tied by two bars to the main island. The enclosed lagoon is a long narrow one, extending the whole distance between the bars. The map indicates considerable filling on the sides of the lagoon (C. S., 821).

Massoncello point, Italy, upon the southern end of which Piombino is situated, is an example where the enclosed lagoon has been completely aggraded by a river delta, that of the Cornia River (Ital., 119, 127).

VI. *Vanishing Island* (Adolescence). — After an island has become land-tied, it continues to waste away by the action of the sea and subaerial forces, until a stage is reached when the island is gone and nothing but the tombolo which connected it to the mainland remains. This stage must of necessity be a short one, for the unconsolidated tombolo will be rapidly consumed. This feature would be one of late adolescence. Theoretically we should expect to find single, Y, cuspate, and double tombolos remaining after the islands had been consumed. The three examples which appear to be surely in this stage are all cuspate. This form is probably the one which best resists the sea, and each of the others is easily converted into the cuspate.

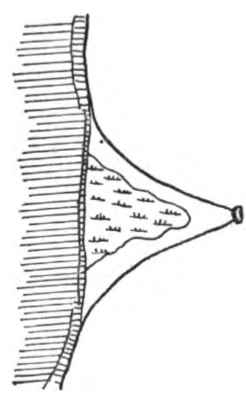

FIGURE 17. Vanishing Island; Diagram of a Cuspate Tombolo. Similar Stage found in Sandy Point, Block Island, Rhode Island.

Cuspate Tombolo: Block island, Figure 17. — The type cusp whose position has been determined by a former island is Sandy point, Block island (C. S., 356).*

At the southern end of Revere beach (C. S., 337; G. S., Boston Bay, Mass.) there is a cuspate projection where a drumlin was formerly tied on and has now been consumed.

Uvita point on the western coast of Costa Rica (H. O., 1035) is a cuspate foreland whose position is apparently determined by rocky islets off the point. This seems to be a case where the cusp is completely tying the island when the island itself is practically destroyed.

VII. *Straight Coast* (Maturity). — The mature stage of island-tying is where the islands and their connecting tombolos are completely consumed

* See Livermore's History of Block Island, 1877, 175.

by the sea. Therefore the straight coasts of Jutland, Italy, etc., as given on page 246, are the forms of the stage next succeeding that of the vanishing island.

Complex Cases of Tying. — Many of the actual examples of island-tying are not simple. A great variety of combinations occur in nature, but only three will be here considered, viz. where several tombolos unite a group of islands, where rivers surround islands with their waste, and where slight movements of the land have assisted tying.

Samsö Island is composed of two higher portions joined by a lower narrow neck (Denm., Samsö). The central portion of this neck is heath and forest, presumably overgrown marsh, bounded on either side by gently curved shores. These curves also indicate tying and complete filling, for the coast farther north and south has not such smooth outlines, indicating that the present position of the land has not been maintained for a time sufficiently long to develop such curving shorelines. The left hand end of the eastern bar is complicated on account of numerous small islands.

Three islands in Lenox cove, Tierra del Fuego (H. O., 455[a]).

West of Magdalena bay an island between cape Corso and Entrada point is tied to another island at cape Lazaro (H. O., 621, 644).*

Marambava mountain, 2066 feet high, has a twenty-mile tombolo extending to the mainland of Brazil, which close to the shore is broken by a tidal opening. A spit from the tombolo inside of Sapetiba bay is growing toward Jaguanao island (H. O., 488).

In Boston harbor there are three groups of islands tied by numerous tombolos (C. S., 337; G. S., Boston, Boston Bay, Mass.), viz. the Winthrop, the Quincy, and the Nantasket groups. Marshes occur in all three, indicating adolescent development.

Sidi bon Said (Tunis, VII, VIII, XII, XIV, XX, XXI) is on an island which is tied to the Tunis mainland by three bars. The central one is 5 to 8 kilometers broad, 10 kilometers long, and has an elevation in places of 10 or 12 meters. Whether this broad isthmus was originally two tombolos enclosing a lagoon, or was made land by elevation, is not certain from map inspection. Later, however, two tombolos have been built from either end of the island, enclosing between them and the earlier built isthmus two lagoons, Sebkhat er Riana and Lac de Tunis.

Leucate (Fr., 255) is an island of Oligocene strata, tied by one tombolo to the mainland, and has also a wing-like bar on both the right and left sides. These wing-bars are built up from the bottom in large measure, according to the indications given by the right-angled abutment of the left end of the right bar against Leucate, and a similar abutment of the left bar against the older land near Port Vendres (Fr., 258). The stream deflections indicate alongshore motion to the right, which is also suggested by the offset of the right wing-bar by the left.

The island of Cette (Fr., 233), of Jurassic strata, is tied by the wing-bar from the left side of the Rhone delta. To the southwest the volcanic knob of Agde is more

* In regard to dislocation as a probable cause of these islands, see W. Lindgren, Proc. Cal. Acad. Sci., 1888–90, I. 173, II. 1, III. 26, and references there given.

completely surrounded by the aggraded detritus of recent times (Fr., 244, 245). The latter may never have been an island.

Berneray island in the Hebrides is made up of several higher portions connected by sandy areas (Scot., 89).

A group between Brandon and Tralee bays (Ireland, 161).

Eddy island is a composite island, in which there are two examples of lagoons almost included by tombolos (Ireland, 114, 115).

Several islands at the head of Galway bay seem to belong to this class (Ireland, 115).

The type of islands tied to the mainland by delta growth is seen in lough Swilly (Ireland, 11), where Inch Top island, 732 feet high, appears to be joined to the mainland on the east side of the bay by the detritus borne down by the small streams. Other knobs to the southeast of Inch Top hill were possibly tied in a similar manner.

The islands of Paleozoic, Mesozoic, Tertiary, and eruptive rocks are surrounded by the delta deposits of the Danube (Taf. III. Jahrb. k. k. Geol. Reichs., XL., 1890).

From San Pablo point to Richmond point is an island completely joined by marshland (C. S., 5581). In this case streams have evidently aided the tidal currents in filling in between a former island and the mainland.

North head, McKensies head, and various other islands at the mouth of the Columbia river (C. S., 681[a], 640), are seen upon inspection of the more detailed charts and Mr. Davidson's sketches * to be tied together to form cape Disappointment, which is in turn tied to the mainland at Chinook point.

An example in which slight elevation may have helped island-tying is seen at the mouth of the Medjerda river (Tunis, VII, XIII, XIV, XX).

Öland and Gjol are becoming land tied by river and tidal deposits, probably more tidal than river, since the elevation of the land from which the streams come does not exceed 75 meters (Denm., Nibe).

An example of complex island-tying is seen on the chart of San Quentin bay, Lower California (H. O., 1043). It would appear that the earliest tying was done when the land stood lower than at present, for some of the bars outside of the salt lakes are cliffed.

10. Bay-bars.

An Adolescent Feature. — Shore development of a submerged region has been studied as regards island-tying; a second important feature is now to be considered. It has been shown that when shore-grade is attained detritus will be transported along the beach at the foot of cliffs, and tombolos connect many islands with the mainland. As the headlands are attacked faster than the bay heads on account of their more exposed position, wing-bars will frequently be formed of the detritus from the cliffs. This special form of bay-bars will be considered under Winged Beheadlands.†

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* Pacific Coast Pilot, 1889, 451.

† See page 213.

The sea also erodes the bottom and supplies material for the bar. The proportion of bottom to side supplied detritus will vary exceedingly. With a deeply dissected, steep coast, the proportion of material from the headland will be large, while in a slightly drowned region, developed to past-maturity in the previous cycle, there will be more material under water above wave-base, and therefore a greater proportion of bottom detritus. There are so many variables which enter into this problem, — viz. initial form, prevailing winds, strength of currents, height of tides, radius of curvature of eddies, structure of land, etc., — that it is difficult to predict where a bar will be built across a bay. It may be said, however, that the sea is not satisfied with an irregular shoreline, and in its attempt to reduce the land to a submarine platform it will straighten the shoreline in order better to attack the land. The curve that a given shore will take depends upon the forces acting at that point.

In one place wings will extend from the projecting headland, in another the currents will build a bar across the mouth of the bay, in a third the bar will grow from a point between headland and bay-head, while in a fourth place the alongshore action may be so weak or the bay so broad that the sea will begin to fill at the head. In this fourth case any delta filling will go on at the same place as the accumulation by sea action.

When the bay-bar is completed, and there is transportation of material practically all along the shore, shore-grade is attained, and the period of adolescence in shore evolution is reached. The narrow and broader bays behind the bars are gradually filled by river, tide, and wind. Where the river activity is strong enough, it pushes a delta beyond the bar. Maturity is reached when the bays are filled and the headlands cut back so that the initial shoreline is lost. From this time forward the sea, satisfied with the shore curves, eats farther and farther into the land with the intention of reducing all that stands above wave-base to a monotonous submarine platform.

The classification of bay-bars here given is not a satisfactory one. The separation into stages of development is only partial, for more facts of observation are needed. The location of the bar in the bay, which depends upon the ratio of alongshore to on- and offshore currents, as well as upon the form of the bay, has been used to make three types of bay-bars. Under each of these, stages of filling occur, all centring about the attainment of shore-grade, and therefore bay-bars may be limited as a class to a period extending from late youth to early maturity. Bay-bars are characteristic of adolescence.

A. *Bar across Mouth of Bay: Lake Ontario*, Figures 18, 19. — Several bays on the eastern shore of lake Ontario are closed by bars, whose form indicates more bottom than alongshore action, there being

FIGURE 18. Bay-bar across Mouth of Bay, Lake Ontario.

no dominant offset and overlap. This indication is confirmed by the observations of the currents, many of the courses of observed bottle drifts having ended on these bars.*

Instead of looking at these sandbars as barriers to keep the sea out of the bays,† let us regard them as built by the sea in order to prevent the wasting of its force dashing into the indentation, where the delta growth will finally be victor, and in order that the sea may be able to concentrate

* Surface Currents of the Great Lakes, U. S. Dept. of Agriculture, Weather Bureau, Bull. B, Washington, 1895.

† See Geikie, Scenery of Scotland, 1887, 186.

its force upon the more exposed coasts, by having a simpler coastline upon which to work.

(1) *Bay but little filled* (Youth–Adolescence). — Bay-bars are forming across three bays on the Oldenburg sheet (Germ., 60). Two of these are on the southern side of Fehmarn island and the third is south of Grossenbrode. In Orther bay transportation is from the left, but in the other examples it is about equally from right and left headlands.

Gruber bay is enclosed by a bar (Germ., 60, 84). The deflection of the outlet, Dahmer-See, to the left indicates a dominant current from the right.

Stettiner bay is closed by a bar which shows a very beautiful series of aggradation shorelines (Germ., 89, 90, 91, 92, 120, 121, 122, 154, 155, 187). The dominant current is indicated by offsets, overlaps, and stream deflections to be from the left. The contest between river and tidal currents on the one hand and alongshore current on the other is clearly shown. A study of details on the ground in connection with these expressive general maps ought to bring out many features of the progressive steps in the formation of bay-bars. Islands are included in this bar and thus complicate its form. Usedom island is made up apparently of several individuals, and Wollin island is in large part a portion of the drowned mainland and not the later built foreland.

Three bays formerly arms of Hochwachter bay are enclosed (Germ., 59). The indications are of a dominant current flowing from the left.

Several examples from Kiel northward (Germ., 39, 58).

Warnemünde is built on a bay-bar (Germ., 86).

Kurische and Frische bays (Germ., 1, 3, 8, 9, 15, 16, 29, 30, 48, 49, 50, 71, 72, 73).

Garder, Dolgen, Leba, Sarbsker, and Zarnowitzer are enclosed to form lakes or lagoons (Germ., 25, 26, 44, 45, 46).

Vietzker lake (Germ., 43).

Vitter lake (Germ., 66).

Jamunder and Buckower lakes (Germ., 65).

Kamper lake (Germ., 93).

Horst-Eiersberger lake (Germ , 92).

Bankel-damm is shut in by a bay-bar (Germ., 13). Transportation is about equal from right and left according to the map indications.

Schlief-see is closed by a bar growing from the right, for on that side the curve of the cliff is continued in the line of the bar, while on the left the bar abuts abruptly against the oldland, forcing the stream under the left hand bluff (Germ., 13).

The Sejrslev headland has a right and left wing growing across bays (Denm., Lögstör).

A cuspate bar extends from the left hand side of Horsens fjord toward a rock near Alro island (Denm., Skanderborg).

Across the mouths of some ten drowned valleys, between the Dnieper and the Danube rivers on the Black sea, bars have grown (Rus., 33; Atlas Univ., 88). More than half of them are completely closed by the sea action. The low mean annual rainfall in this region, 15.83 inches at Odessa,* would cause weak stream

* E. Loomis, Contributions to Meteorology, revised ed., 1889, 151, Pl. XXIII.

action. The waves and currents, though weaker on the inland sea than on the open ocean, are relatively stronger than the streams, for they are able to close these bays. The absence of ocean tides, which tend to keep open inlets into bays, aids this shutting up.

Across the western end of the sea of Azov a bar has been formed (Atlas Univ., 88; Rus., 48, 62) which has nearly rectangular junctions with the mainland, indicating that it has been built largely from the bottom of the sea.

Lituya bay, Alaska, has the right spit offsetting the left. Glaciers now descend to sea level in various arms of this fjord (C. S., 8451).

Thomas bay, Alaska, has bar forming between Vandeput and Wood points (C. S., 733).

On Amaknak island, Alaska, the spit has grown southward from Ulakhta head more than half way toward Rocky point (C. S., 821).

Coburg peninsula west of Esquimalt roadstead, Vancouver island (H. O., 1806).

Tomales bay, California (C. S., 681), has a bay-bar extending three quarters of the way from the left toward the right side of the bay, thus indicating a dominant current from the left.

Willapa bay, Washington (C. S., 6185), shows incurving spits at the end of the bar, pointing up the river.

(2) *Bay more or less filled* (Adolescence), Figure 19. — Silting up of the bay enclosed by a bar progresses rapidly, as engineering works testify. Streams, tides, and winds fill this quieter water with waste. The changing conditions of alongshore transportation will be shown by the advance or retreat of the shoreline of the bay-bar.

A bar has grown from the right across the mouth of Mobile bay (C. S., 187, 188). Successive positions of this bar are indicated by some eighteen sympathetically curving dune ridges with intervening stream or marsh. The offset here indicates a dominant current from the right.

Tampa bay, Florida (C. S., 176, 177), shows overlap from right to left, thus indicating a dominant current from the right.

The overlap of the right bar at the mouth of the harbor of Rio Grande do Sul, Brazil, indicates a prevailing current from the right (H. O., 1191).

A bar is built from Palmia point to Gorda point across the drowned valley of San José river, Lower California. Its southern point overlaps and offsets the northern portion, indicating a current from the left (H. O., 635).

Several bays on Monte Gargano, Italy, show nearly complete filling (Ital., 157)

South of Söby on Årö island Vidsö bay is closed and the lagoon is considerably filled with marsh. A nip decreasing in height toward the bay-head is clearly shown on the German map (Germ., 24; Denm., Faaborg). These two surveys differ decidedly as to the amount of filling.

On the eastern side of the southern point of Falster island (Denm., Gjedser) the sea has a curving shoreline of large radius upon a low sandy coast behind which lies an enclosed lagoon, to the west of which is an area of higher land. The offsets and stream deflection indicate a prevailing current from the right Bötonor lake has a bordering belt of marsh, and there are other patches of marsh between this lagoon and the eastern shore. All the above facts suggest the growth of a bar across the mouth of an open bay. In front of the artificial sea wall, built to protect the coast, the map shows a belt of sand, as if the sea was even now building out in places.

On the western coast of Langeland and at the southern point are several enclosed bays partly filled (Denm., Svendborg, Gulstav). The offsets indicate movements in both directions.

The bays on the southwest side of Chirikof island, Alaska, show several stages of filling (C. S., 9191, old number 796). The sea built five bars from headland to

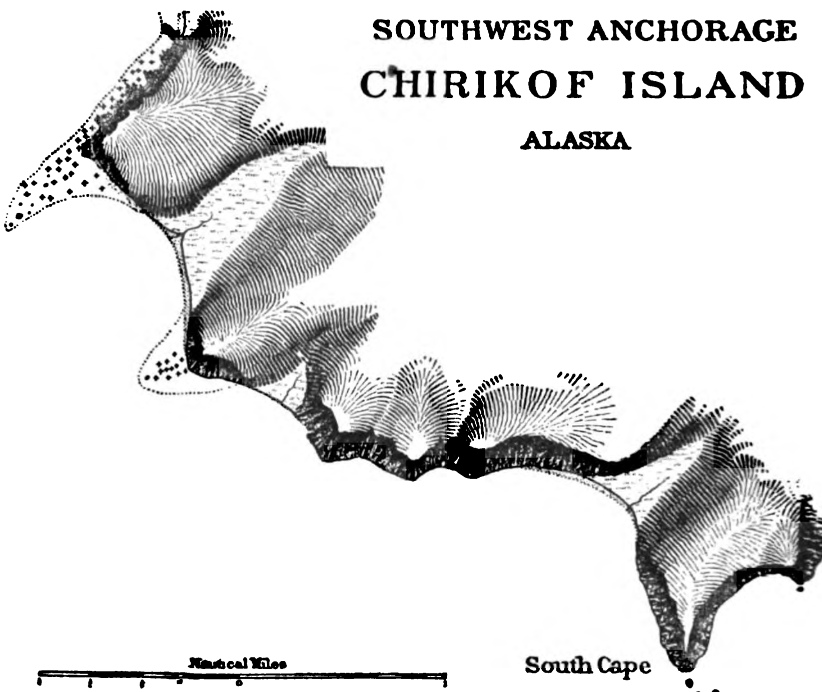

FIGURE 19. Nearly Mature Filling of Bays.

headland, in swinging curves satisfactory to itself. In the broadest bay there still remain two lagoons, but the others are completely filled (Fig. 19).

Kiska harbor on Great Kiska island, one of the Aleutian islands, has three bays showing three stages of filling. In the central one there is a large lagoon completely enclosed, in the northern one a small lagoon remains, and in the southern one the area back of the bar is completely converted into marsh (C. S., 9191). The alongshore current is here probably from the left, witness overlap of bars to the right, and streams crowded to right side of bays.

(3) *Bay filled* (Maturity). — The last few examples in the previous section are as near to mature forms of this kind of bay-bars as have been found in the present study. Mature stages of bay-bars merge into mature ria-deltas so closely that one can hardly separate them upon the map. When the bay is filled, the stream mouthing in the bay will attempt to push forward its delta, and the shore form

then depends more upon the ratio between stream and current, than upon the attempt of the sea to bridge across the bay. The day of the bay-bar is over.

B. *Bar in Middle of Bay.* — The form of the bay or the strength and position of the currents may cause a bay-bar to grow from the side of the bay, at some point between the head and mouth of the bay. If the growth of the bar is due largely to alongshore action, a spit will extend from the side of the bay; but if the bottom action is dominant, the bay-bar will abut nearly at right angles against the coast of the bay.

(1) *Bay but little filled* (Youth-Adolescence). — Yakutat bay, Alaska, has a bar forming at point Turner, about half way between mouth and head (C. S., 8451).

Chignik bay, Alaska, has spit growing from right side of bay only (C. S., 8891).

Kachemak bay, Alaska, has spit grown about half way across from its left side (C. S., 766).

Salinas bay, Lower California, has a bar enclosing a salt pond into which there is little or no drainage (H. O., 850).

Inverness or Moray firth (Scot., 83, 84, 93, 94) has a spit growing from either side, of which the left one is considerably near the mouth of the bay. The Dornoch firth (Scot., 94, 103) has spits in similar positions.* The writer questions whether the position of these spits indicates a dominant current in these two bays from the left.

Hagios Nikolaos bay (Attica, XVII). Current probably from right.

The small bay, Hejlsminde, on the eastern end of the boundary line between Denmark and Schleswig is shut in by a bar whose curve is continuous with that of the coast to the north, indicating a current from the right. On the left side of the bay there is nearly a right angle between bar and coastline, indicating that the sea builds here mainly from the bottom (Germ., 7; Denm., Skamlings Banke).

(2). *Bay more or less filled* (Adolescence). — Marathon bay in Greece (Attica, XVIII, XIX). The former courses of the Marathon river and the overlap and stream deflection to the right indicate the prevailing current to be from the left. On the right side of the bay the bar abuts against the oldland forming nearly a right angle with Kynosura point. This fact indicates that the bar is built mainly from the bottom.

Mosvig bay (Denm., Skamlings Banke) shows a smoothly curved bar continuous to the right and left with the shore curves, indicating filling from either side. The dominant direction of alongshore current is indicated as from the right by the stream deflection to the left. Behind the bay-bar the lagoon is almost completely filled with marsh.

The sea has built Tent moor and Barry links upon the two sides of the firth of Tay (Scot., 49) and the rectangular junction of the bay filling with the bay sides indicates that the building has been done from the bottom. Deflection is toward the central channel, where the relatively strong tidal currents interrupt the formation of a typical bay-bar.

Dornoch firth is a similar example (Scot., 93, 94, 102, 103).

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* Geikie, Scenery of Scotland, 1887, 186, 187.

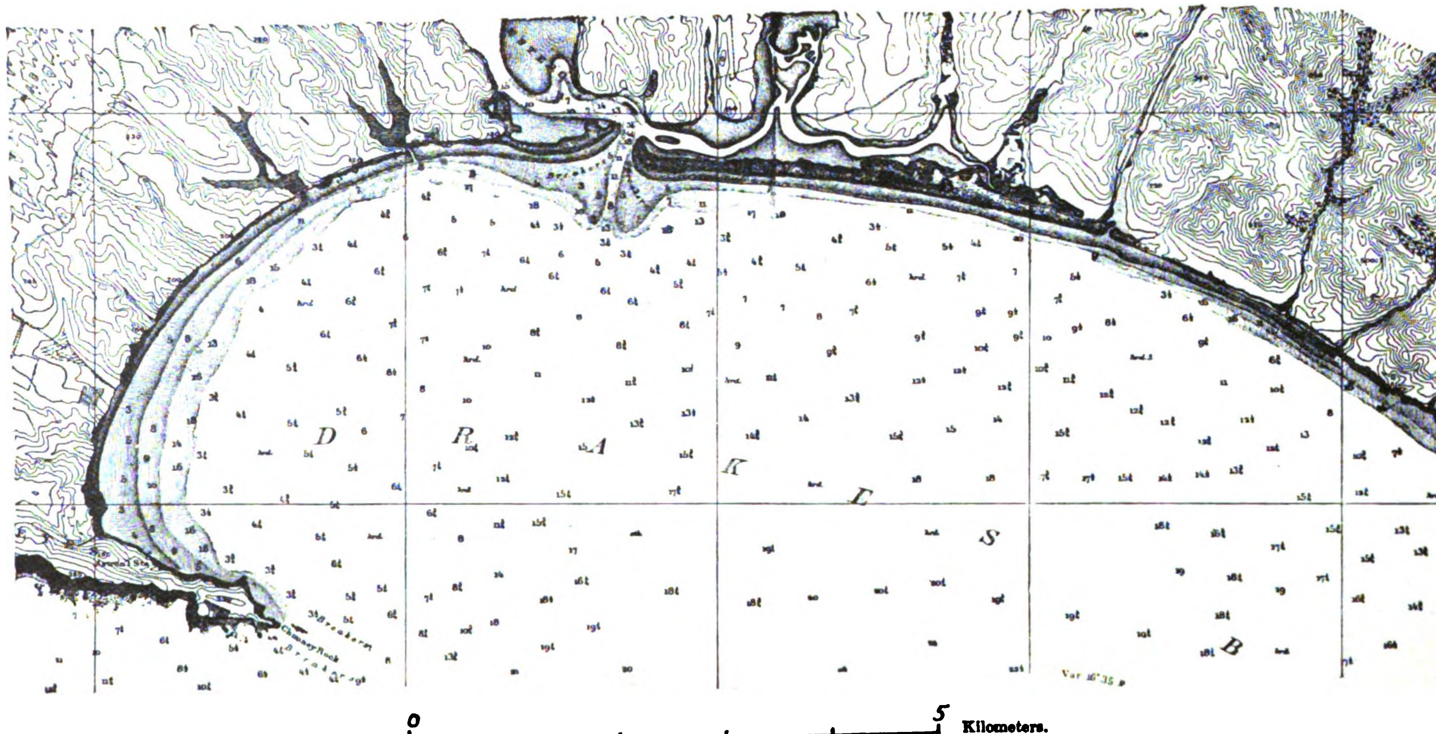

FIGURE 21. Bay-bar near Head of Bay: Drakes Bay, California. Nip in Drakes Estero.

(3) *Bay filled inside Bar* (Adolescence). — Under this heading are included several cases in which it is impossible to tell whether the bar originally was found where it now stands or whether it began near the bay head.

Procchio and Biodola bays (Elba).

The gulf of Salerno has a bar from Salerno across to Agropoli, inside of which it has been filled by river and tidal action, forming a rich delta plain with only a few remaining marshy places (Ital., 185, 197, 198).

Gulf of S. Eufemia (Ital., 241). Current from the left is indicated by deflection of streams to right.

From Palmi, Italy, across to Nicoteca a bar extends from the right headland to a point across the bay half way between the left headland and the bay head (Ital., 245, 246). Direction of current is probably from the right.

Bay of Phaleron southwest of Athens (Attica, III). The bar is largely produced by the action of the sea on the bottom, for the shore curves at its two ends are not continuous with curve of the bar.

Vari bay (Attica, VIII). This also shows sea bottom action.

Hanö bay (Swe., 6). Dominant current from the right.

C. *Bar near Head of Bay: Drakes Bay*, Figures 20, 21 — At the head of Skelder bay (Swe., 8) a bar is built chiefly from the bottom, since the bar curve abuts sharply against the two sides of the bay, and streams are deflected to the right on the right hand side and to the left on the left hand side of the bay, thus indicating currents in either direction from the centre (Fig. 20). There is evidence of very trifling transportation along the sides of Skelder bay.

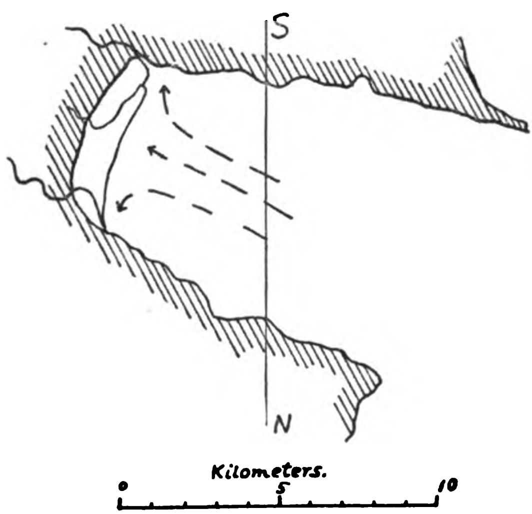

FIGURE 20. Diagram of Bay-bar at Head of Bay; dominant Bottom Action: Skelder Bay, Sweden.

The indications from right-angled abutment at both right and left sides of Laholms bay (Swe., 8, 13) are that the bar is built mainly from the bottom with but little transportation along the sides of the bay. The stream deflections from either side of the bay toward a probable oldland island now included in the bar indicate currents toward the centre. This is in marked contrast to the last example, taken from the same coast.

Nearly as typical an example is in Dingle bay (Ireland, 172) where the bottom action is dominant, though there is indication of some transportation from the right side of the bay.

There are many cases of bay filling of this type along the Irish coast (Ireland, 7, 9, 15, 51, 62, etc.).

Dundrum and Dundalk bays on the west shore of the Irish sea (Ireland, 61, 70, 71, 81, 82).

Drakes bay, California (Fig. 21), is a broad open bay, with a bay-bar growing near its head. Delta filling is now progressing between the nip and the bar.

Another typical example of the head of a broad bay being aggraded by sea and streams working together is seen in the gulf of Taranto, Italy. From the swinging outline of the shore the sea action is seen to be stronger than the river action, the deltas are either rounded or stunted. The dominant direction of current is seen by the offsets to be from the left (Ital., 212, 201, 202).

At the southwest corner of this gulf where the Crati river enters, the shore is also aggrading. Here the several streams form a great confluent delta, whose form is modified by the sea (Ital., 221, 222, 229, 230).

In Wachusett cove, Alaska, the curve of the shore at the head of the bay was nearly satisfactory to the sea forces, acting therefore sea and river fill at the same point. The great rise and fall of the tides, 18 feet, doubtless prevents the formation of a bar across the mouth of the cove from Bluff point (C. S., 784).

Nateekin bay, Alaska (C. S., 821).

In the upper portion of the valley of San Francisquito bay, Lower California (H. O., 638).

Harbor of Acapulco, Lower California (H. O., 872).

San Juan del Sur, Nicaragua (H. O., 934).

Manzanilla and Santiago bays, Mexico (H. O., 915).

Filling is shown on west coast of Central America (H. O., 1016, details in 1025–1033).

Todos Santos bay, Lower California (H. O., 1046).

Several bays on the east coast of Scotland are of this type, Lunan, Montrose, Aberdeen, Cruden (Scot., 57, 77, 87). The beaches abut sharply against headlands of irregular shorelines, an indication of bottom building.

Sinclairs and Dunnet bays (Scot., 116) similarly indicate growth from the bottom.

Several beaches on Tiree island (Scot., 42) are of this type.

Magilligan Foreland, Figure 22. — Magilligan point (Ireland, 6, 12) is a bay-bar which combines some of the characteristics of tidal cusps with the normal bay-bar features. From the cliff on the left of the bay a gently curving beach extends to the end of the point, indicating growth by alongshore transportation from the left. McKinneys bank points up

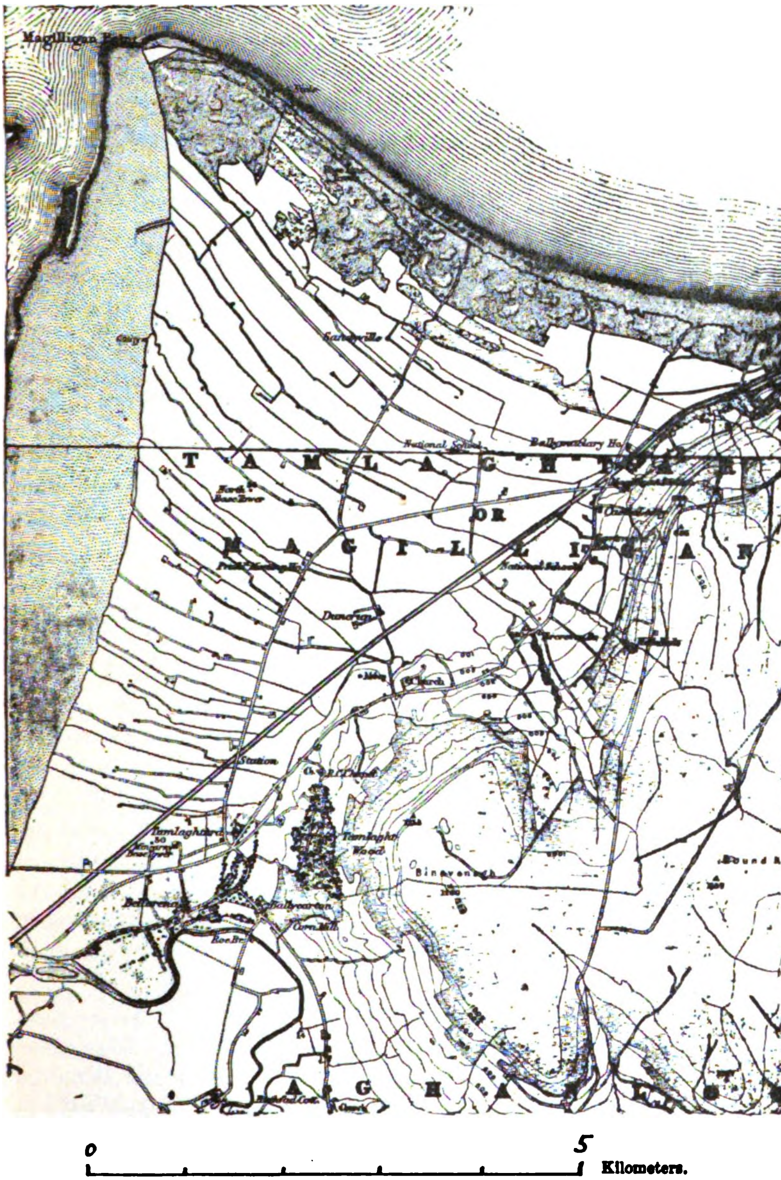

FIGURE 22. Magilligan Foreland, Ireland.

lough Foyle from near the tip of Magilligan point, and its straightness and length suggest a fairly constant and strong tidal current through the inlet, three fourths of a mile broad, between the point and the right side of the bay.

This foreland has the cuspate outline appropriate to a tidal cusp, but on the bay side it shows no line of growth. Back of the present ocean beach, however, are seventeen roads which curve sympathetically with the shoreline of to-day. These roads are not parallel lines, but each curve is nearly parallel with the two on either side, departing just enough from parallelism to make a systematic series, changing gradually from a direction a few points south of west to one nearly northwest and southeast. Between almost every pair of adjacent roads is a ditch, whose course is systematically accordant with the direction of the roads. These culture lines are not constructed in a haphazard manner, and their orderly arrangement suggests a series of successive curves of higher and lower ground. Such a systematic series indicates lines of growth. If this indication be true, then this cuspate bay-bar began some five miles farther up the bay, and has advanced by some seventeen steps to its present position.

As said above, the bay side or right side of the cuspate bay-bar shows no aggradational line of growth. Each of the roads and ditches ends at the high tide line, forming transverse features in respect to the bay shoreline, while the same are longitudinal with respect to the ocean shoreline. This abrupt ending, together with the continuous curve of the bay shoreline, suggests that the sea may have shaved off the ends of these presumable former beaches.

As confirming the above hypothesis for the formation of Magilligan point, it is observed that the cliffs, some 200 feet high, where the alongshore action changes from cutting to aggrading, continue as a nip behind the Magilligan foreland. This cliff is progressively lower toward the supposed earlier formed portion of the foreland. This would be expected, since the portion of the cliff which was exposed for a shorter time to sea action, other things being equal, would have the less height.

The dominant current from the right, which is indicated by the form of this bay-bar, is possibly due to a backset eddy between Islay island and Ireland. The ocean current flowing from the southwest along the west coast of the British islands * could cause such a backset eddy in this locality.

* Krümmel, Uebersichtskarte der Meeresströmungen, 1886.

11. Winged Beheadland.

A Combination of Bay-bar and Cliff. — One of the striking features of adolescent shore development is the winged beheadland. Where the projecting headland has been cut back and transportation has taken place in both directions, spits extend to the right and left from the headland. The winged beheadland is made up of a cliffed headland and two bay-bars, one extending to the right and the other to the left; and this combination of wing-bars with a headland beheaded is so striking a form, and one so characteristic of depressed regions developed to adolescence, that these forms have been grouped separately.

Type: Long Branch, N. J. — From Sandy point to Barnegat inlet is one of the finest winged beheadlands to show the method of formation. The records since the Europeans came to America show the cutting back of the cliffs on the headland, and the shifting of the wings on either side. From the slope of the land above the cliffs upon the headland, it is seen that the land probably projected several miles beyond the present cliffs. The consumption of this land supplied more waste than the sea could immediately carry offshore, and it was temporarily deposited, forming Sandy hook and Island beach. The left wing was probably built in large part from the bottom, and represents the offshore bar of the low New Jersey shore. The cliffs upon Navesink highlands represent the nip, cut before the barrier of Sandy hook was formed.

Other Examples. — Cape Cod is an example of a winged beheadland which projects far into the sea, so that the wings do not extend across bays on either side. The series of changes of the right or Provincetown wing, as indicated by the form, has been worked out by Professor Davis.*

Another typical example is seen on the island of Laaland (Denm., Nakskov, Maribo, Dannemare).

Sejrslev headland (Denm., Lögstör) shows the same form.

Sylt island off the west coast of Schleswig has a right and left wing extending respectively toward Amrum and Röm islands (Germ., 11, 20, 21, 35, 36). The Miocene headland (Geol. Eu., 24) is separated from the rest of the oldland by the drowning, and is therefore somewhat different from the type example.

Insel Poel and Halbinsel Wustrow north of Wismar have both developed wings (Germ., 85, 116). These wing-bars have been curved strongly back toward the mainland.

Similar wings from islands are seen farther north (Germ., 41, 63).

Usedom island is made up of two main headlands with wings (Germ., 89, 90, 121, 122).

Wollin island (Germ., 91, 121, 122).

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* Proc. Amer. Acad., 1896, p. 303.

Samland with its wings protecting Kurische and Frische bays (Germ., 3, 8, 15, 16, 28, 29, 48, 49, 71, 72).

The Pomeranian headland has its right wing enclosing several lagoons, while its left wing is growing into Danziger bay (Germ., 25, 26, 27, 44, 45, 46, 47).

West of the Crimean peninsula there is a very striking winged beheadland (Rus., 33). The initial shoreline is very evidently changed by the cutting back of a projecting headland and the extension of wing-bars, behind which the less altered shoreline is seen. Although the map is not of the highest quality, the scale is small, and the geology of the region is unknown to the writer, he has no hesitation in classifying this feature on account of its typical winged outline.

North of the left-hand wing of the last example is a somewhat similar area, whose origin is, however, not so clear. The outline is similar to a winged beheadland, but the headland is full of small lakes, and it seems probable that it is a part of the Dnieper delta drowned by a late episode of depression. A submergence is indicated by the drowned rivers to the northwest (Rus., 33; Stelier, 48).

12. Tidal Cuspate Forelands.

Location and Description. — In regions of drowned valleys, long inlets, or narrow sounds, where the two opposite shorelines are roughly parallel to each other, cuspate deposits of sand frequently occur, when shore development has reached an adolescent stage and transportation along-shore has begun.

These forelands project from one quarter to three quarters of a mile into the sea, and vary in breadth between the same limits. In some cases the cusps are long and narrow, while in others they are short and broad. Frequently they more or less completely enclose lagoons, but in some instances there is no included water body, or if there was one it has become filled. The curve of the two outer edges of these sand deposits is concave toward the water, and is a continuation of the curve at the base of a shore cliff. These two concave curves intersect in a marked cusp, which is sometimes typically pointed, though in other cases the tip is rounded. The axis of these forelands projects approximately at right angles to the shoreline, and also at right angles to the general direction of the tidal currents in the inlets.

Type, Figure 23. — West point, north of Seattle, Washington, will be taken as the type, and, after giving its description and discussing the method of its formation, others differing in details of form will be considered. Magnolia bluff, two miles northwest of the city of Seattle, has a gently swinging curve, doubtless quite satisfactory to the current here prevailing. This curve continued forms the right boundary of the West point cusp. The curve on the west side of the foreland is in like manner a continuation of the curve of another cliff (C. S., 658; G. S., Seattle).

On the inside of the cusp there is a faint cliff where the coast was nipped after the initial drowning. The central lagoon is nearly all converted

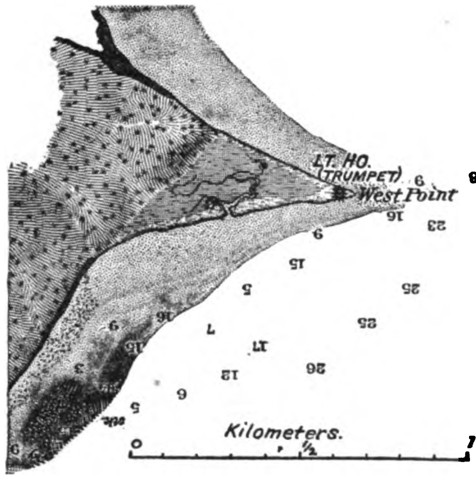

FIGURE 23. Filled Stage of Tidal Cuspate Foreland: West Point, Washington.

into marsh, a small tidal inlet remaining on the left side with a few small ramifying branches. The cusp is very perfectly formed by the intersection of the two curves in a sharp point.

Sand point in Narragansett bay is nearly as typical in form and position as West point. This point projects from the eastern side of Prudence island (C. S., 353) into a channel less than two miles broad and from 10 to 17 fathoms deep, 5½ fathoms off the point of the foreland. This cusp is smaller than the average tidal cusp, and it shows no included lagoon or marsh. Mr. J. B. Woodworth says that the ice in winter overrides this cusp, and thus any indications of embryonic form would be obliterated. The secondary cusp on the left side of the foreland appears to be due to the collection of sand about rocks or piles driven into the sand.

A profile has been drawn from another typical cusp, point Wilson (C. S., 6405), north of Port Townsend, Washington. This drawing (Figure 24) shows the relation of the foreland to the older mainland. The broken line indicates the probable initial form of the land following the depression which inaugurated the present cycle of shore development. The "foreland" quality of the cusp is here clearly seen; it is constructed

by transportation and accumulation in front of the nipped oldland. Although plotted from the soundings and contours about point Wilson, this figure will serve as a general profile of all the cusps of this class. Where the initial slopes were less steep, less contrast is seen between the oldland and the foreland.

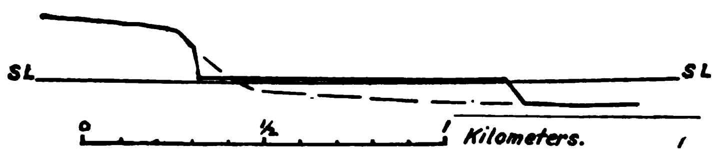

FIGURE 24. Profile of Tidal Cuspate Foreland: Point Wilson, Washington.

Tidal Hypothesis. — Before considering other cusps which differ somewhat from West point, let us look for a moment at what might be expected to result in narrow channels with sides nearly parallel. Waves would attack this inner shoreline to a greater or less extent at all points. When adolescence is reached in the process of shore development, and waste is supplied faster than it can all be carried offshore, it will be transported and deposited somewhere.* The great system of ocean eddy currents is not able to affect this inner as it does the outer shoreline. Local winds must produce small currents proportional to the size of the water bodies, but these will be so weak in narrow channels that their effects will be lost in those of even moderately strong tidal currents. Thus it seems safe to conclude that the probable agent of transportation in such channels is the tidal ebb and flow.

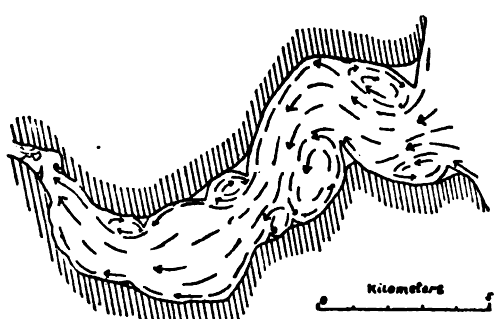

FIGURE 25. — Ideal Scheme of Tidal Inflow: Port Discovery, Washington.

An ideal scheme of inflowing tide, with the eddies which would probably accompany it, is given in Figure 25. Where the movement is least in the triangles of comparatively dead water between the several

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* Compare pages 176–178.

members of the circulatory system, the deposition would take place. In the majority of places the outflowing tide would reverse the direction of flow and transportation of shore waste, therefore the combined action of ebb and flow would shape the tidal foreland so that its central axis would be at right angles to the general direction of tidal flow.

The cuspate forelands, which are mentioned under the three following heads, are arranged in three stages of progressive development, — the V-bar stage, the lagoon-marsh stage, and the filled stage.

V-bar Stage. — A much younger stage than that of West point is seen on the same sheet at Meadow point. Here the bars surround a relatively large lagoon, which apparently has hardly begun to fill. The form of this bar is what Mr. Gilbert has called V-shaped.*

Various examples on the east coast of Port Discovery (C. S., 648) show V-shaped bars enclosing lagoons. The majority of forelands in this bay have their greater extension alongshore. Beckett point, however, has its length normally at right angles to the shoreline.

At point Monroe, near Port Madison, Washington (C. S., 663), a looped bar encloses a lagoon somewhat similar to those just mentioned. The shore drift is here all from the left, and the curve of the bar is convex seaward. At point Jefferson farther north on the same sheet there is another convex bar enclosing a lagoon where the drift has been from the left, as shown by the continuation of the cliff curve in the bar. These two examples do not give the typical cuspate form.

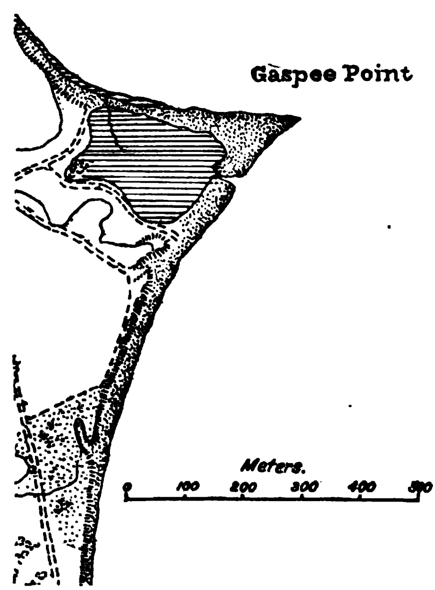

FIGURE 26. Lagoon-marsh Stage of Tidal Cuspate Foreland: Gaspee Point, Narragansett Bay, Rhode Island.

Lagoon-marsh Stage, Figure 26. — Various stages of lagoon filling are shown on the Port Townsend sheet (C. S., 6405, old number, 647). Walan point foreland has considerable area of lagoon, and still maintains open connection with Port Townsend. At point Hudson there remains an unfilled lagoon, but its connection with the sea is lost. At point Wilson a small lagoon now exists, while at Kala point the lagoon

* Lake Bonneville, 57, 58, Pl. VII.

is practically converted into a marsh. On the foreland at Marrowstone point the sand dunes have almost obliterated the marsh.

On this same Port Townsend sheet the rounding of the point of the cusp may be studied. At point Wilson the concave curves intersect in a slightly rounded cusp, while at Kala point the cusp is more blunt, and Walan point is decidedly rounded. The curves at point Hudson have a long radius, so the sides of the cusp are nearly straight, and since they meet at nearly right angles the foreland has a broad flattened appearance. The curve on the right side of Marrowstone point changes from a concave to a convex form, so that it gives that side of this foreland a snubbed look.

Sand point, projecting into Popof strait, Alaska (C. S., 8891), is a fairly typical example of a cusp with enclosed lagoon. The point is here somewhat blunted, more on the southern than the northern side. This foreland as mapped is evidently a piece of made land, built forward in the process of shore development.

A typical example is seen in New Dungeness harbor, Washington (C. S., 646), where inside of the beautiful hooked spit forming the harbor the foreland projects with a very sharp point.

Gaspee point (Fig. 26) in Narragansett bay (C. S., 3047) may be taken as a typical example of this lagoon-marsh stage.

A rounded cusp with completely enclosed lagoon occurs near the mouth of Horup bay (Germ., 24; Denm., Faaborg). Upon the same sheet there is a typically sharp pointed cusp projecting from the north end of Ärö island. This projects at right angles to the general shoreline, but the belt of water is here so wide that the wind-made currents probably have as much controlling influence as the tidal, possibly more.

Filled Stage, Figure 28. — West point, Washington.*

Dungeness point† on Romney marsh, England, is a cuspate projection into the English channel (Eng., 4).

In the eastern entrance to Magellan strait, South America, is one of the largest known forelands of this class. Westward from cape Virgins and south of a nipped cliff 100 to 300 feet in height projects from five to six miles a second Dungeness, named by some British seamen in recognition of a form similar to that of the great English sand cusp (H. O., 443, profile in View A).

Sandy point, Magellan strait, South America (H. O., 450ᵃ), is another example.

On Douglas island opposite Juneau, Alaska, is a tidal cusp at low water, while at high tide it is covered (C. S., 734). The rise and fall of tide at this point is 18 feet.

Sextant point, San Quentin bay, Lower California, is apparently a cusp built out between two rocky headlands (H. O., 1043).

Estauques point, Venezuela, is a long narrow cusp (H. O., 1087).

Alice point, on the bottom of the foot of the Italian boot, is a foreland which shows no included marsh. Its axis if projected across the gulf of Taranto would touch the extremity of the heel, as if its existence showed the attempt of the sea to close the gulf (Ital., 231).

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* See page 214.

† Topley, Geol. of the Weald, 1875, 211, 303; F. Drew, Romney Marsh, Mem. Geol. Sur. Eng. and Wales, 1864; F. P. Gulliver, Dungeness Foreland, London Geog. Jour., 1897, IX. 536–546.

South of Rettin there is a somewhat irregular cusp (Germ., 84).

A cusp projects into Der Bodden from the southeastern point of Rügen island (Germ., 89).

There are several cusps inside of Frische and Kurische bars (Germ., 3, 8, 15, 16, 29, 48, 49, 71, 72).

In Vejle fjord (Denm., Fredericia), there are several cuspate projections, often called "Hage" or hook, whose form and position indicate eddies in the tidal in and out flow.

At the mouth of the Elbe river, west of Cuxhaven, where fortifications now stand, is a low projecting point, a foreland of this class (Germ., 110).

Two broad, completely filled cuspate forelands occur in the Kieler and Eckernförder bays respectively (Germ., 58). Friedrichsort is built upon the former, while the latter lies six kilometers east of Eckernförder.

Cebú, on an island of the same name among the Philippine islands, is built on a point apparently of this same nature (Spain, Bol. XIII, 1886, Lám V, 1 : 100,000).

A cusp with irregular outline of "Schaaf Land" (Pasture?) is built in front of one of the Holland dikes (Holl., 8).

Landskrona (Swe., 4) is built upon a low cuspate point, which appears to be a foreland of this class. As there are shoals off the point it may be that this is a cusp resulting from the tying on of an island which is now cut away.

Between Helsingborg and Råå there is a rounded foreland, an embryonic tidal cusp (Swe., 4).

A cusp near the head of Skelder bay (Swe., 8) curves around from the usual position at right angles to the tidal currents and points toward the mouth of the bay. The presence of oldland may account for this, but the form of the cusp indicates a change in direction of growth from the normal position at right angles to the shoreline to one where a spit is growing from the cuspate point toward the right.

Methods of Growth. — It would seem from inspection of the maps that it was the more common thing to enclose lagoons, though in some places the growth has evidently begun at the mainland and progressed outwards. In False Dungeness harbor some of these cuspate deposits are seen which do not appear to have ever enclosed any lagoons (C. S., 646). Three of the cusps on the inside of the Coatue Spit, Nantucket, have no lagoons, but as the other two have, and since they are nearer the end of the spit and hence probably later formed, it is quite likely that the earlier formed forelands also began with lagoons (C. S., 111, 343; G. S., Nantucket, Mass.).

Professor Shaler has ascribed these Coatue cusps to tidal whirlpools. He says: "From a superficial inspection it appears that the tidal waters are thrown into a series of whirlpools, which excavate the shores between these salients and accumulate the sand on the spits." *

* Bull. U. S. G. S., No. 58, 1889, 13.

Among these filled cusps are included doubtless those which have passed through the V-bar stage as well as those which have grown by gradual out-building, since from present knowledge it is impossible to separate the two groups. With better maps and descriptions of the cusps a later classification will make closer distinctions.

Theory confronted with Fact. — After this general survey of the varying forms of cuspate forelands selected from the many examples in the narrow water bodies of the world, the following generalization may be made. However varied the form resulting from the local conditions, tides, relief of oldland, etc., the axis, or a line drawn from the point of the cusp through the centre of the foreland, is always at right angles to the general direction of flow of the tidal currents.

Where there are strong tides, as in Puget sound, Chesapeake bay, and Narragansett bay, there are numerous and typical cuspate forelands; while in Albemarle sound the range of tides is less than one foot, and here few sandy points of a cuspate form occur.

Thus the facts of observation seem to correspond with the principal requirement of the theory. Studies of the existing currents in regions where these forelands are found are now needed to further test the tidal hypothesis. From present knowledge this seems to be the best working hypothesis.

Two methods of growth are suggested. In one the outline of the foreland is early given by a V-bar, and later this enclosed lagoon is progressively filled. In the other the foreland grows by successive additions to the mainland. The first appears to be by far the larger class; though the examples of the latter are liable to be confused with the filled stage of the first class.

Between the narrow channels and the open sea there are all gradations in size of water bodies, so we should expect to find forelands built by combination of tidal and wind currents in different proportions. Such cases have been referred to in Del Faro point, Ärö island cusp, and Alice point.

13. Bay-deltas.

History of a Drowned Valley. — Bay-deltas fill drowned valleys. The term *ria*, from the Spanish, may be advantageously used to cover all types of subaerially carved troughs, including von Richthofen's fjord, ria, dalmation, and liman types.* After depression, the stream in youth

* Führer, 305-312. Compare use by Penck, Morphologie der Erdoberfläche, II. 562-582.

builds a delta at the head of the ria or drowned valley, in adolescence it pushes it well forward, and in maturity it has completely driven the sea out of the valley and thus obliterated the initial shoreline of depression. Bay-deltas, or ria-deltas will here be grouped under the three heads, young, adolescent, and mature.

Type Young Bay-delta: Loch Fine, Figure 27. — The type is seen in loch Fine (Scot., 37) where Fine river has begun to fill the drowned valley. Shira river farther west has also begun to fill, and later the two streams will join their deltas, filling up the lower portion of the ria. At the head of this long bay the delta form is practically free from complication due to sea action, which in so many cases influences the form of filling.

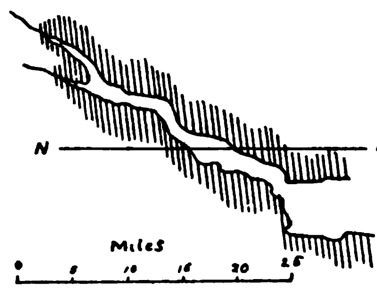

FIGURE 27. Young Bay-delta: Loch Fine, Scotland.

Other Young Bay-deltas. — Many occur on the northwestern coast of Spain, from which locality the generic term "ria" was taken (Stieler, 33; Spain, Bol. VII, 1880, Lám. D).

Strath Beag at the head of loch Eireboll (Scot., 114).

Loin water at the head of loch Long (Scot., 38).

At the heads of loch Lomond (Scot., 38, 46); loch Awe (Scot., 45); loch Striven (Scot., 29); loch Etive (Scot., 45); loch Maree (Scot., 92); loch Broom (Scot., 92); loch Duich (Scot., 72); etc.

Tomales bay,* California, a well marked "ria," shows delta filling at its head (C. S., 631).

Drago delta, Austria (Austr., 25, IX). This stream is small, and has not yet filled much of the ria, Canale di Leme.

Type Adolescent Bay-delta: Dwamish. — The Dwamish river pushing forward its delta to fill Elliott bay is the type. Seattle, built upon the mainland along the margin of both the delta and the unfilled bay, has a splendid combination of elevated locations for residences, flat delta land for future business blocks, and a water front on deep tide water. As the delta grows forward the city will occupy it, probably accelerating its advance, and transfer the shipping interests farther down the bay (C. S., 651; G. S. Seattle).

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* See page 196.

Other Examples. — The larger streams in the Puget sound region, notably the Skokomish, de Chate, Nisqually, Puyallup, and Snohomish (C. S., 6450, 6460, 690, 644).

The Tay river has filled about half of the valley which the firth occupied after the depression (Scot., 48).

Kyle of Durness and kyle of Tongur (Scot., 114).

Ruel strath (Scot., 29, 37).

Sachaig strath (Scot., 37).

Clyde delta (Scot., 38).

Carron delta (Scot., 92).

Torridon delta (Scot., 91, 92).

Scotland gives also many other examples.

Bilbao ria is partly filled (Spain, Vizcaya, 1892, Lám. 1; Spain, Bol. III, 1865, Lám. D).

Mobile bay is being rapidly filled by waste from the Alabama rivers, although the delta front is some 30 miles from the mouth of the bay (C. S., 188).

The ria-delta in Irondequoit bay is not so far advanced as the Dwamish, and is perhaps on the border line between the periods of youth and adolescence. The mouth of the bay is closed by a bay-bar, so the stream will be able to push forward its delta undisturbed by the waves of lake Ontario.

Halkjaer (Denm., Nibe).

Randers (Denm., Mariager).

Vejle is built on the delta growing forward into Vejle fjord (Denm., Fredericia).

The stream emptying into Rands fjord (Denm., Fredericia).

Several streams entering into Odense fjord (Denm., Hindsholm, Nyborg).

Quieto and Dragogna rivers, Austria (Austr., 24, IX).

Arsa delta, Austria (Austr., 25, X).

Bado delta, Austria (Austr., 26, X).

In St. Jördals fjord (Nor., 47, C).

Ler river (Nor., 15, C).

The Dniester (Rus., 33).

The Gedis delta in Asia Minor (Brit. Ad., 1523, Map II, Dr. C. Cold, Küstenveränderungen im Archipel, München, 1886) has grown, even in historical times, into the gulf of Smyrna, and will soon geographically cut in two the harbor of Smyrna and leave that city without communication with the Ægean sea.

The above mentioned catastrophe has happened to Heraclea and other places south of Smyrna on the coast of Asia Minor, where the Mæander has nearly filled its ria (Brit. Ad., 1555; Cold, loc. cit., Map III).

Type Mature Bay-delta: Simeto, Figure 28. — South of the volcanic mass of Etna, the three rivers Simeto, Dittaino, and Gorna Lunga have built a common flood plain and delta of recent alluvium. This is a beautifully mapped illustration of the ideal form of a delta-filled bay (Ital. and Sicily, 269, 270, 273, 274). The filling may have been contemporaneous with a slow sinking of the region, or the space now occupied by the flood plain may be simply what was not filled with the lava. The form is so typical however that it is given as the best mapped

example of a mature bay-delta, although there is some doubt as to the early stages of this example.

Other Examples. — In Chehalis river, Washington, the delta has filled not only the drowned valley, but has also considerably filled North and South bays between the nipped coast and the bar (C. S., 643).

A similar case is Willapa river, Washington (C. S., 681[a], 642, and 6180).

Solkjoer river has completely filled its ria (Denm., Skamlings Banke), except for a small pond. The deflection of the mouth is to the left, indicating a current from the right.

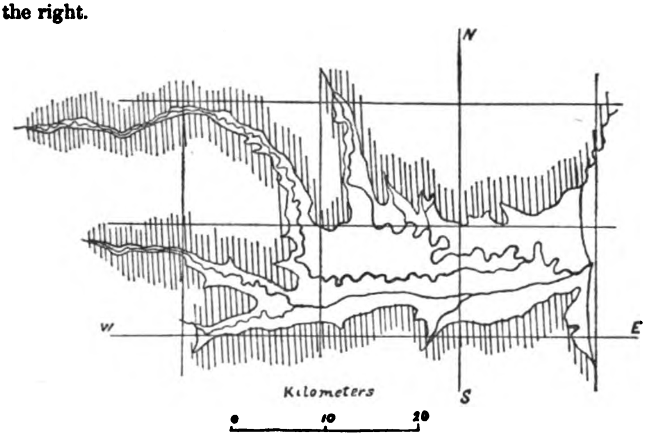

FIGURE 28. Mature Bay-delta: Simeto, Sicily.

Taubaek (Denm., Nibe).

Kastbjerg (Denm., Mariager).

Narenta river has nearly filled the drowned portion of its valley (Austr. 33, XVII).

The Guadalhorce river has filled its ria; also the Vélex (Spain, Bol. XVII, 1991, Lám. A; XVIII, 1892, Lám. A).

Lake Bay-deltas. — Lakes whose basins are portions of river valleys frequently show, at the end where the stream enters, deltas of similar form to those mentioned above. These deltas show almost complete river intention, since ocean currents and tides do not affect them, and the narrow water bodies do not permit the winds to stir up very destructive waves.

The delta of the Ticino river in lake Maggiore, Italy, is a typical example (Pet. Geog. Mitt., Erg. XIV., Nr. 65, 1881, Taf. III.).

See also the delta of the Rhone in lake Geneva (Carta Geologica d' Italia, Roma, 1889); that of the Aare in lake Neuchâtel (Swiss, VIII, and Carta dell' Italia Superiore, by R. Lenzinger, Zürich); etc.

Bonneville Bay-deltas. — Almost all the streams entered lake Bonneville through mountain gorges, and the detritus of the Bonneville epoch was deposited in these narrow estuaries forming bay-deltas, the water at the Bonneville level having entered the previously eroded valleys. When the water fell the detritus was carried away, leaving no deposit to mark the Bonneville shoreline in these larger streams.*

14. Deltas.

Ratio between Sea and River Activities. — The shore changes caused by delta growth depend on the ratio between sea and river activity more than upon any other factor; and deltas would therefore be typically developed either after uplift or depression. The area of a delta is a measure of time since the beginning of a cycle. A large river will soon build a great delta, a precocious infant; but the delta will attain its maximum area at some period in late adolescence or maturity, after which the delta will diminish in area by the degrading of the river. A smaller stream has a similar maximum area, though its dimensions at any given stage are always less.

The life of a river is in a sense to be considered apart from the cycles of coastal plain development and also as distinct from the other shore changes, though its life is intimately connected with and a most important part of both sets of processes. The river's aim is to convey the load given it by the land to the sea. Of itself it would build forward a lobe for each distributary, the shifting of these distributaries on account of the upbuilding causing in time a broad fan-shaped deposit, so well shown in the confluent delta of the Hoang and Yangtze rivers.

The sea, on the other hand, desires a straight shoreline. The delta intention is opposed to its attack upon the land, and therefore the sea aims to cut off the front of the lobes and carry the delta waste out to sea, depositing it beyond wave attack or below wave-base.

The form of a delta front does not indicate sharply the stage of the cycle in which a given region stands. The relative strength of sea and river may cause a given form of delta front at many stages in the life history of a region. The river activity is increasing from birth toward maturity, so that in the case of any given river there will come a time of maximum activity, when the river will be best able to push forward and build a lobate delta into the sea. This time, however, may not be the time when there is the greatest likelihood of the formation of such a

* Gilbert, Lake Bonneville, 154.

lobate delta, for the activity of the sea is also a variable, and it may happen that the ratio between the two activities is more strongly in favor of the river at some time before or at some time after its period of maximum activity. For example, if the time of maximum activity of the sea on a given shore occurs at a later stage than the time of the maximum activity of a certain river, the largest ratio in favor of the river will probably occur considerably before its maximum; while if the sea's maximum occurs at an earlier stage of shore development, and is decreasing at a more rapid rate than the river's activity, the ratio in favor of the river will be greater after its maximum is passed.

It may be that the sea action is so strong off any river's mouth that the river never is able to carry out its intention. Indeed, this seems to be the case in a large proportion of the rivers of the world. The sea is relatively stronger than the river in all cases except where the volume of the river is exceptionally great, as in the Mississippi, or where the mouth is protected from the stronger sea attack, as is the case of the Po at the head of the comparatively narrow Adriatic.

Delta Stages. — In the initial stage deltas do not exist. At any time after the beginning of a cycle, a delta may be built, whose size will depend far more on the volume and drainage area of the river than upon the time since uplift.

In the cycle following uplift a delta of a certain frontal outline may occur at various stages, and the forms appropriate to successive stages have not been worked out, because of the many complications of the problem, some of whose factors are indeterminate. Deltas doubtless follow a normal succession of forms under the various conditions. This has been shown to be true in the case of bay-deltas. A delta foreland of any considerable size would not be found projecting from an initial coast, where the valleys of all the larger river systems had been submerged. Until maturity of shore development has been reached, large delta forelands would consequently not be expected upon depressed regions.

Credner. — Dr. Credner's monograph on Deltas * is to-day, nearly twenty years after its publication, the most complete source of information about the deltas of the world. While his descriptive portions are classics, the theoretical conclusions of the text seem open to question. Dr. Credner apparently looked at deltas as phenomena requiring some common cause which would account for their presence or absence. He

* Die Deltas, Pet. Geog. Mitt., Erg. XII., Nr. 56, 1878.

found that deltas were not due necessarily to a large amount of sediment; that they are not explained by the greater or less velocity of current; that their presence is not determined by a deep or shallow sea in front of the mouth of the river; that they are not explained by the presence or absence of an offshore bar; that they occur even where tides are strong; that "the presence of a controlling ocean current (Tiber, Rhone) does not alone suffice to prevent the formation of deltas"; and, finally, that deltas are not prevented by the wind. He then goes on to show that delta growth is aided by slow elevation and hindered or prevented by gradual depression. He concludes that relative elevation of the land with respect to the water is the controlling cause of delta growth.

Such slow elevation of the land is surely an aid to delta extension, but it is only one of the factors which work together in the determination of delta growth; and cannot be considered necessary, in the opinion of the present writer, for the aggradation of a coast line by rivers.

Further Study. — The subject of deltas offers a very attractive field for investigation. The writer has not been able to make out nearly as much as he had expected to in regard to the stages of development shown by deltas. He is convinced that each delta goes through appropriate stages, but the variables are so many, and vary between such wide limits, that the laws of development are not clearly seen. Vigorous advancing deltas are characteristic of maturity, following both uplift and depression. But the maximum of delta growth may be either before or after this period, as shown above. Bay-deltas have been separated from the rest, as they show characteristic stages following depression. When better understood, other deltas will fall into their appropriate stages.

Classification. — Deltas are here classified, not according to stage in cycle, but according to ratio of activity between river and sea. The examples of shore development by delta growth are arranged in the following series.

1. Lobate deltas: (*a*) unilobate; (*b*) multilobate.

These show the river intention successful.

2. Cuspate-lobate deltas.

The river intention is in these deltas predominant, but the sea action prevents typical lobes.

3. Cuspate deltas.

The river mouths at the point of intersection of two shore curves, concave seaward.

4. Rounded deltas.

The shore currents prevent the cuspate extension.

5. Stunted deltas.

The stream in this case is able to alter but slightly the shore curve.

6. Blocked streams.

The sea here builds a bar closing the mouth of the river. This ratio was recognized by Dana,* who used the term *blocked*.

1. *Lobate Deltas.* (*a*) *Unilobate type.* — In this class are those deltas in which a single lobe is formed by a single stream, showing pure river intention. No very typical example has been found.

The delta of the Mæander (Brit. Ad., 1555; Dr. C. Cold, Küsten veränderungen im Archipel, München, 1886, Map III) has now a typical unilobate front, projecting from the nearly straight front of the almost filled ria.

The Ebro is of the general form of the unilobate delta, slightly modified toward a multilobate type (Credner, loc. cit., 17; Spain, Bol. XVI, 1889, Lám. A).

(*b*) *Multilobate Type.* — The type is the Mississippi. This classic example is so well known, and has been so frequently given to illustrate successful river intention, that a description is here unnecessary.

The Kilia or northern distributary of the Danube (Rus., A; Credner, loc. cit., 28).

The Volga (Rus., 114; Credner, loc. cit., 16; Pet. Geog. Mitt., IV., 1858, Tom. V.).

The Atrato (Credner, loc. cit., 5).

The Po (Stieler, 28) shows the river intention dominant, with partial cutting off of the more exposed lobes.

The Gedis delta in the gulf of Smyrna (Brit. Ad., 1523; Cold, loc. cit., Map II; Credner, loc. cit., 11).

The Rhone (Fr., 233, 234, 235, 246, 247) has a form midway between the Mississippi and the Tagliamento.

2. *Cuspate-lobate Deltas.* — The type is the Tagliamento at the head of the Adriatic (Austr., 22, VIII, IX; 23, VIII, IX). The river intention is plainly seen in the form of the delta front, but the alongshore currents prevent the formation of typical lobes. Former positions of the delta front are indicated by the lines of villages on the higher ground. Three of these lines are seen west of Palmanova (Austr., 22, VIII). On the earliest shoreline are situated Gonars, Castions, Flambro, Rivolto, Codroipo, and intermediate places; on a later and less clearly marked line are Castello, Paradiso, Torsa, Ariis, and Rivignano; while a third stage in the growth of the delta is indicated by the road connecting St. Giorgio with Latisana. These lines are more or less perfect divides across which but few streams cut, and these few gather the many small watercourses from the areas which represent the filled lagoons. The transition from lagoon to marsh, to wet meadow, and finally to a rich lowland plain capable of high cultivation, is beautifully shown in going inland from the Adriatic east of the Tagliamento.

The Danube delta (Rus., A) shows many former channels with recent changes. That the river has been pushing forward is also indicated by the marshy, reed-covered surface, but thinly populated.†

Fraser river, British Columbia (H. O., 961).

* Manual, 3d ed., 1880, 683.

† Draghicénu, Jahrb. k. k. geol. Reichs., 1890, XL. 409.

Holland (Atlas Univ., 26) is in large part a great confluent delta formed largely by the Rhine and adjacent streams.

The Nile is a multi-cuspate-lobate delta (Brit. Ad. 2578, 2630; Credner, loc. cit., 2).

8. *Cuspate Deltas.**— The typical example of a cuspate delta is given in Figure 29. The two gently swinging shore curves, concave seawards, with their dune-lined beaches, are the work of the sea. At the point of intersection of these two curves the river empties. The form of the land shows that, if it were not for the river, there would not be any cusp here, as there is no projecting point in the oldland to cause eddies in the currents. The evidence from the turning of the mouths of the small streams both to right and left indicates that the direction of current motion alongshore is probably sometimes in one direction, and sometimes in the reverse. The smaller streams on each side of the river's mouth are deflected away from the point of the cusp, indicating that the delta mass divided an onshore current and turned it to the right and left, carrying the river sediment from the river along the shore. Farther from the river, both on the right and left sides, there are streams deflected toward the mouth of the main stream. There is here evidently no dominant movement in either direction along the shore.

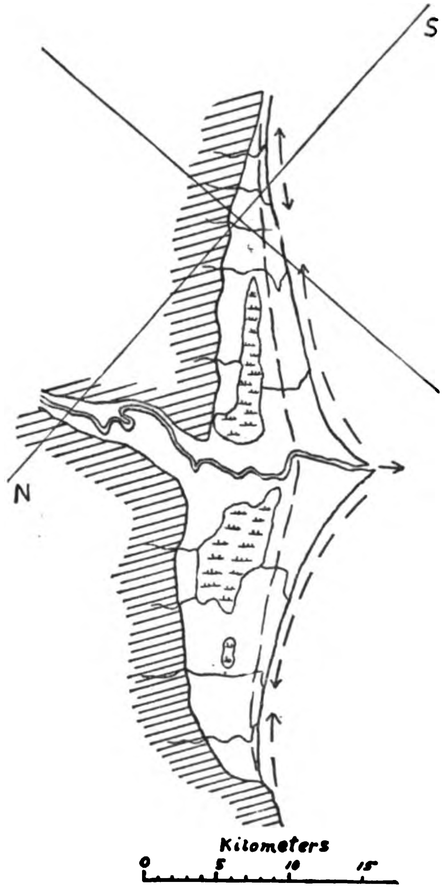

FIGURE 29. Typical Cuspate Delta: Tiber, Italy.

A former stage of the delta is indicated by the ridge of geologically older material, which is represented in the figure by the broken line. This earlier stage of the delta front is seen to have a rounded outline. This suggests that formerly there was a dominant movement alongshore. Back of this former shoreline are seen areas of marsh, filled lagoons, or lowland behind the old beach. Since this leap from some still earlier position of the shoreline, the forward growth seems to have been

* For fuller discussion, see Bull. G. S. A., 1896, VII. 417–421.

gradual, for no long slashes of swamp are shown. This type is the Tiber (Ital., 149; Carta Geologica della Campagna Romana, Roma, 1888).

The Angitola delta (Ital., 241) extends a small cuspate point beyond the curve of the bay-bar, as if the stream crossing the bar was relatively strong enough to divide the alongshore current. It has been found impossible to pick out from the other examples of cuspate deltas given below, any which were later stages of this embryonic type. The maps give little more than the form of the latest stage of development. The forms should be studied on the ground, in order to see what was the embryonic condition. This study is analogous with what is done by the paleontologist when he peels off the outer shell of an Ammonite in order to discover its embryonic form.

In both the Biferno (Ital., 155) and the Ofanto rivers (Ital., 165) the deflections indicate a current from the right at present, though formerly the deflection was in the opposite direction, according to the indications from inland form.

In the two following examples of deltas, Volturno (Ital., 171, 172, 184) and Ombrone (Ital., 127, 128, 135), the streams are deflected in both directions, thus indicating no dominant current alongshore.

The current is probably from the left in front of Alento delta (Ital., 141) and from the right at Neto delta (Ital., 238).

Düna river (Rus., 18) has a cuspate foreland projecting into the Gulf of Riga. The deflection of the Aa river to the left indicates a strong current from the right at the head of this gulf.

The Aa de Livonie, east of the Düna, also has a cuspate outline (Rus., 13).

Punta Arenas, a Chilean settlement, South America, is built on a foreland made by combined action of river and sea (H. O., 450[a]). Deflection is to the left.

A variation from the typical form is seen in the hooked point of Ausable delta in Lake Champlain (C. S., 554; G. S., Plattsburg, N. Y.).

In the Volstrap at Aaeby (Denm., Frederikshavn) the southward deflection of the mouth indicates a prevailing current from the right.

The Danzig mouth of the Vistula (Germ., 70) shows deflection to the right.

Kolberg is built on the cuspate delta of the Persante (Germ., 93). The evidence along this coast is for a current from the right.

Many of the discharge sluices emptying into the Zuyder Zee have built cuspate deltas, and though aided by artificial means, the form is so typically cuspate that they are included in this category (Holl., 15, 16, 21, 26, 27, 32).

4. *Rounded Deltas.* — The type of this class of deltas is that of the Arno (Ital., 104, 111). The delta front is bounded by a curve convex seaward, changing into the shore curves concave seaward. In contrast with the case of the Tiber the river is here not strong enough to separate the alongshore current into two eddies. The current swings around the delta, and gives it a smoothed outline in place of a cuspate.

Fortore delta, Italy (Ital., 155). This sheet shows a portion of the former channel, *fiúme morto*, on the left wing of the delta.

The Sinni, Agri, and Basento deltas (Ital., 212, 201). Dominant current from left.

The Sele delta, Italy (Ital, 197, 198). Dominant current from right.

Sangro and Trigno deltas, Italy (Ital., 148). Currents uncertain.

Vomano, Saline, and Pescara deltas, Italy (Ital., 141). Dominant current from right.

Savuto delta, Italy (Ital., 236).

Crati delta, Italy (Ital., 222). Current from left.

Trionto delta, Italy (Ital., 230). Currents in both directions.

The Fiumenica delta, Italy (Ital., 231). Mouth deflected to right.

The Esk delta upon which Musselburgh is built (Scot., 82) shows no dominant current.

The deflection of over 2,000 meters of the ditch-like stream near Lyngsaa suggests current from right (Denm., Frederikshavn).

The northward deflection of the mouth of the Liver river with its rounded delta, indicates a current from the right (Denm., Hirshals).

Marathon delta, Greece (Attica, XVIII). Current from the left.

Rega (Germ., 92); Wipper (Germ., 66); and Stolpe (Germ., 44). All three indicate a slightly dominant current from right.

Rion delta, at the eastern end of the Black sea (Rus., 80; Stieler, 49). Streams are deflected to the right and to the left from the mouth of the river.

The Rio Grande (C. S, 212) has filled a considerable portion of the lagoon, enclosed farther north by Padre island or the great Texan offshore bar, and is now advancing in front of the bar at Bagdad, having in recent geographic time abandoned the distributary running toward Boca Chica inlet.

The Llobregat (Spain, Barcelona).

5. *Stunted Deltas.* — In a fifth class of deltas the relative strength of the stream is so much less than that of the sea that the shoreline curves around the front, making almost no change in its curvature at the mouth of the river.

An example is seen in Figure 30, where the Cavone empties into the Adriatic (Ital., 212), making a very slight convexity. The dominant current in the gulf of Taranto is from the left.

The Soltane makes but faint projection into the gulf of Tunis (Tunis, XXI). Easterly current.

The Simeto delta, Sicily (Ital. and Sicily, 270, 274). The deflection of the mouth is toward the right. The bottom cutting of the sea is judged to be greater than its alongshore action, because the beach abuts nearly at right angles against the lava at Catania and Agnone (Fig. 28).

The Simeri river is cut off without any delta growth (Ital., 242). Deflection is about equal in both directions.

Acate delta, Sicily (Ital. and Sicily, 272, 275). Dominant current from the right.

The delta of Garigliano river, Italy, makes but a faint projection against the sea (Ital., 171). Deflection to right.

Lama d'Arco delta (Ital., 201) and Lato and Lenna deltas (Ital., 202) on the gulf of Taranto, Italy. Dominant current is from the left.

F. Alento, Italy, is not allowed by the sea to build forward its delta (Ital., 209). Current from left, as deflection is to right.

F. Oliva, Italy (Ital., 236).

Several streams on the Catanzaro sheet (Ital., 242). Currents about equally from right and left.

The ditch-like stream 4,000 meters north of Saeby enters the sea with no deflection and producing no apparent alteration in the shore curve; a similar stream six kilometers south of Saeby causes as little alteration in the shore curve, but it is deflected 800 meters to the south, which indicates a current from the right; a third

variety of stunted delta shown on the same sheet is that of another ditch-like stream, one kilometer north of Vorsaa, which produces slight alteration in the shore curve and is not deflected, but the land on the north of the stream decidedly offsets that upon the south, indicating again a current from the right (Denm., Frederikshavn).

Kolkjaer and Brendelsig give no indication as to direction of current (Denm., Aalborg).

Haslevgd is deflected to the south, suggesting a current from right (Denm., Mariager).

Kjul, Ugerby, and Tversted deltas suggest current from right (Denm., Hirshals).

Guadalaviar ó Turia (Spain, Valencia).

FIGURE 30. Typical Stunted Delta: Cavone, Italy.

The Tinto river is strongly deflected to the right and shows very little projection of a delta (Spain, Huelva; Stieler, 35).

The Tet delta (Fr., 255).

6. *Blocked Streams.* — If the sea action is relatively stronger than in the last case it may close up completely the mouth of the rivers (Fig. 31). The water from the typical ponded streams on the Oceanside sheet, California, reaches the sea by percolation through the beach.

The stream intention is often completely blocked by the sea when the water is carried in a deflected course far to the right or left, and such examples have been included in this category.

An example of a blocked stream of a different type from the Oceanside case is seen in the Vistula (Germ., 70, 71, 99, 100). The sea here blocks the course of the river and carries out its intention of a concave shoreline. The main work of the river at present seems to be filling up Frische lagoon into which the main distributaries have been turned, since the aggradation of the drowned valley.

FIGURE 81. Blocked Stream: Oceanside, California.

The delta of El Rincon river on the north side of the ridge south of which the stream flows is an anomalous feature, until one perceives that in the contest between river intention and sea intention the latter has been victorious. A current from the left flowing up the gulf of Dulce is indicated, such current having forced the stream to turn a right angle around the point (H. O., 1036).

Sea intention versus river intention is prettily shown at Coos bay, Oregon (C.

S., 5984). The spit formed by the southward flowing current has crowded the river as far south as possible, close to the cliffs on Coos head.

Another good example of a river forced against a rocky headland by the sea is seen in Garcia river at point Arena (C. S., 661).

Bezirk river is lost in the sand dunes before reaching the gulf of Tunis (Tunis, XXI). Current is indicated from the left.

15. Tidal Scour.

Action in Bays. — Tides as abrading agents are most effective in drowned valleys. The destructive effects of the bore have been much discussed, and more work has been ascribed to this inrush of tidal waters than that for which it is probably responsible. The depth to which tides may scour a submarine channel is still a very problematical question, and the amount of wearing of the shores by the tides is a subject needing study.*

Tides are not here taken up at any length, because the relation of their products to stage of cycle is not as yet shown. The forms of shores as determined by the changing ratios between tidal on- and offshore and alongshore currents is the only point upon which emphasis is here laid. As in the consideration of deltas, this point is dwelt upon because it shows so clearly the importance of perceiving the varying ratios between the several factors that determine shore forms.

Runways. — On flat coasts where there are broad surfaces covered at high and bare at low tide or wide stretches of tidal marsh, there is opportunity for much tidal work. When the main body of ocean water retreats during ebb tide, that portion lying upon the flats must flow off down the easiest path, and thus runways are formed dissecting the surface. Such runways may be broad or narrow, deep or shallow, short or long, etc., according to the values of the varying factors which obtain in any given case. The scouring action may continue below low tide level, to greater depths, the greater the range of tide and volume of water passing through the runways.

The tidal scour if strong would tend to prevent the tying of islands and closing of bays, which are normal features of shorelines in an adolescent stage of development.

Such prevention of island-tying is seen on the Schleswig coast, where from the stage of development indicated by the long wings on Sylt island (page 213), the development of tombolos would be expected. It

* For the discussion of the scouring of tides in estuaries, see papers by the following authors: Bache, Branner, Dana, Ferrel, Mitchell, Shelford, and Sollas.

seems therefore justifiable to infer that in this locality strong tidal runs have prevented the growth of tombolos.

The form of the tidal runway is of the indefinite type of channels, called *insequent* by Professor Davis. A broad tidal flat will be cut by runways forming a dendritic drainage pattern (Germ., 5, 36, 37, 79, 80). Where there are large rivers, the pattern of dissection will show the controlling influence of the master stream (Germ., 109, 110, 111).

Ratio between Tides and Currents. — The relative strength of tidal on- and offshore action and alongshore current action is a most important consideration in the determination of the form of coasts. The form of the North Carolina coast indicates that back-set eddies * are relatively stronger than the tides. The prevailing extension of water bodies is along the shore. These alongshore channels or lagoons are connected with the ocean by tidal inlets which cross the bars, and whose position is constantly shifted by alongshore transportation. These inlets represent the weaker tidal intention working at right angles to the general shoreline, while the lagoons indicate the stronger alongshore action.

Something of the insequent pattern is seen in the ramifying channels inside the offshore bar at Bogue and New River inlets, North Carolina (C. S., 148). Southward along the Carolina coast the alongshore action would appear from the shore forms to diminish in strength in relation to the tidal in- and outflow.

Series of Forms. — It is possible to arrange shores in a progressive series according to the ratio between tidal on- and offshore and alongshore currents. This series is not one following stages of development, but one which is determined by the ratio between two variables, whose average directions of activity are at right angles to each other.

The normal development of shorelines as affected by the sea should however be kept in mind, and allowance made in each example for the stage of development indicated.

When the ratio is in favor of the alongshore current, the forms developed should show extension in the general direction of the shoreline; when on the other hand the ratio is in favor of the tides, the most pronounced shore feature should be development at right angles to the shoreline.

Western Florida Type. — On the western shores of Florida, although the tides are weak, the ratio between tide and current action is inferred to be preponderantly in favor of the tidal, as indicated by the form of

* See page 180, and Bull. G. S. A., 1896, VII. 405.

the shore (C. S., 180, 181). These two sheets show almost no indication of alongshore work. The shoreline is minutely irregular from the dissections of the tidal runways. The bottom is very shallow, the three-fathom line extending on an average eight miles from the shoreline. The average rise of the tide is here 2.5 feet.

The runways off this coast are not so deep nor so markedly dendritic as in the succeeding case, but the stream pattern is very irregular.

Schleswig-Holstein Type. — On the west coast of the Schleswig-Holstein peninsula (Germ., 5, 11, 20, 21, 35, 36, 37, 55, 56, 79, 80, 109, 110, 111) occurs an example of marked tidal scour. The west coast of the Schleswig-Holstein peninsula from the mouth of the Elbe to the Danish boundary is low and flat, with many outlying islands of the same character. The spaces between islands and mainland are occupied by broad flats, bare at low tide, with steep-sided channels dissecting them. Some of these channels are continuations of existing valleys on the mainland, and were possibly cut when the land stood higher. Others however head upon the flats, and appear to be runways cut by the tide. The volume of water covering the broad flats at high tide must have considerable scouring power when confined in these narrow channels, and it has probably cut many new channels and deepened previously existing inequalities.

Offsets, overlaps, and stream deflections indicate a dominant current from the right in this region, whose existence is proved by observation.* Generalizations need to be followed by detailed study and observation of localities. Wherever possible to include facts of local observation, it has here been done, but of many localities there are no descriptions. In the present case it is possible to compare the rate of alongshore current and the range of tides.

The resultant for the year 1880–81 of the northward flowing current along the west coast of Jutland was eighteen nautical miles in twenty-four hours or 0.75 mile per hour.† The rate of flow is probably not so great along the less exposed coast immediately north of the Elbe river. The range of the tides off this west coast of the Schleswig-Holstein peninsula is from 2.75 meters to 3.50 meters (Germ., 20).

The volume of water which flows off these flats must be large on account of the breadth of the area flooded at high tide. The form plainly indicates that with the above ratio between alongshore currents

* H. Mohn, The North Ocean, p. 166, Pl. XLIII.

† *Loc. cit.*, p. 168.

and the tides, and the volume of tidal waters, the tidal in and out flow largely determines the forms developed.

The stage of development of this shoreline is one which shows characteristic features of adolescence. The projecting headland of Sylt island is graded and has characteristic wings on right and left. The sea is now carrying this shoreline landward. The islands of Fano, Röm, and Amrum were at an earlier period graded, as is indicated by their form, and are now locally aggrading, as is indicated by the outlying sand banks built in front of probable former shorelines. This geographic interpretation is found to accord with the geology as given by Dr. L. Meyn.*

The relation of such marked tidal scour to the adolescent stage of development of this coast is not clear. The sequence of tidal forms during successive stages of cycles is a subject needing much further study.

Georgia-South Carolina Type. — In the case of portions of the Georgia-South Carolina coast (C. S., 152, 153, 154, 155, 156) the ratio is less in favor of the tides, although they are still the controlling factor in the development of coastal forms. The shore curves are not continuous for long distances, nor are the offsets arranged systematically. Many tidal channels interrupt the sea beaches. These tidal runways are prevailingly at right angles to the general direction of the shoreline, but there are many connecting channels which run alongshore roughly parallel to the beaches.

With the exception of Bulls bay (C. S., 153), where there are broad flats covered at high and bare at low tide, the runways drain great areas of salt marsh. The detritus brought down by streams from the land, the sands blown by the wind, and the growth of swamp vegetation, as well as the action of salt water upon mud-laden waters, all tend to convert flats into solid land.† The tidal scour is opposed to this filling, and carries off what it can by its runways into deeper water, to be finally built into the continental delta.

The control of tidal runways by large rivers is shown in this region by the Savannah, Broad, and Winyah. Tidal channels are turned toward the stream current in some places, while in others the river fills up the runways with detritus causing the water to flow away from the river, in

* Geologische-Uebersichtskarte der Provinz Schleswig-Holstein, 1 : 300,000, Berlin, 1881.

† See discussion by Prof. Shaler, 6th Ann. Rep. U. S. G. S., 1884–85, 360, 361; and 10th Ann. Rep. U. S. G. S., 1888–89, 261–264.

the same manner that a river higher up in its course causes streams to flow away from the main channel down the slope of the alluvial plain. The gathering is seen in the case of the Broad, and the filling up in the Savannah (C. S., 155).

These tidal runways, which open to the sea in a direction away from the main river, are often no doubt former distributaries of the river, at present kept open by the tides. The river delta phenomena merge into the tidal very intimately in this region, and features are due usually to more than one cause. River, tidal, and current action are here blended, with the indications that the tides are the dominant factor in the determination of the shore forms.

The average height of tides at cape Romain is five feet, while the highest observed tides in this area rise from eight to nine feet.

An example of a ratio similar to the South Carolina type occurs on the north coast of Holland (Holl., 2, 3, 4, 5, 6, 9; Atlas Univ., 33).

Southern New Jersey Type. — Northward from Winyah bay the ratio is in favor of alongshore action. Areas showing some tidal in and out flow, controlled by alongshore action, are seen on the following sheets (C. S., 152, 149, 148, 123).

When the lagoons are nearly filled, as in southern New Jersey, the longitudinal feature of the shore is not so marked. But in this case, the time element must be considered, a stage later than that in North Carolina probably exists, and the ratio between tide and current is not necessarily changed.

North Carolina Type. — The next ratio taken to illustrate this progressive series is where the youthful shoreline shows continuous offshore bars, broken only at intervals of several miles by tidal inlets. Examples are seen on the following sheets (C. S., 122, 138, 145, 146, 147, 150).

The tides in the region of Hatteras rise from one to three feet, while the rate of the currents is various, being much affected by storms.

Texas Type. — A final example in this series may be taken from the gulf of Mexico, on the opposite side from which the first was taken. On the east side of the gulf the ratio seemed to be in favor of pure tidal action; on the west, however, the alongshore action appears to be practically uninterrupted by the tides, and has determined the form of the Texas bar, continuous for 102 miles (C. S., 210, 211, 212).

"The tide is almost always less than a foot, and its time is very variable and uncertain. Storm tides are the only important ones." (C. S., 211.)

16. Cliffs.

Nip. — A very characteristic feature of the early stages following both uplift and depression has been shown to be the first cut, or nip, made in the initial coast, before the formation of an offshore bar succeeding elevation or foreland succeeding depression, the presence of either of which protects the coast for the time from further attack.

Examples of Nips. — Back of an offshore bar a nip is usually observed, though the scale of many maps is too small to show so faint a cliff.

Nips are also seen in many regions which have been depressed. Drakes estero (Fig. 21).

Brackenridge bluff and Stearns bluff are nips on the initial coast of Grays harbor, Oregon (C. S., 648).

Back of Willapa bar, Washington, the irregular coast was nipped (C. S., 642 and 6185).

There is a nip north of Empire City, Oregon (C. S., 637).

In Chignik bay, Alaska, inside of spit (C. S., 8891).

Behind the marsh in Brown cove, Alaska (C. S., 704).

Both east and west of the delta of the Dwamish river, Washington.

Powder point, Duxbury, Captains hill, and High cliff, Plymouth, Mass., were nipped before the sea built Duxbury and Long beaches (C. S., 338).

Back of the bar in San Rafael bay and behind the dunes in the filled valley of San Francisquito bay, Lower California, nips are seen (H. O., 638).

Todos Santos bay, Lower California (H. O., 1046).

Behind the marsh on Santa Maria island, Chile (H. O., 1209).

In Frische and Kurische bays (Germ., 3, 8, 29, 30, 49, 72, 73).

Irregular Cliffs (Infancy–Youth). — Cliffs occur along ungraded shores, where there is no protection afforded by bars or other forelands. These are characteristically jagged and irregular in youth, becoming more and more gently curved as the graded shoreline of adolescence approaches.

The actual height of these cliffs upon ungraded coasts depends almost entirely upon the character of the country submerged. The 1,000-foot cliff of North cape, Norway, where the waves dance up and down and accomplish but little abrasion, is young; while the low cliffs upon the islands east of Stockholm are also youthful.

Caves are characteristic of this stage of development. Fingals cave is cut by the sea in the sheets of igneous rock in the drowned western coast of Scotland.*

Cliffs cut in the older Paleozoics of the southern uplands of Scotland, 200 to 300 feet high (Scot., 33, 34, 41).

* Geikie, Scenery of Scotland, 1887, 218, 219.

The western side of Lewis island has a very jagged outline (Scot., 98, 104).

Many fine examples occur on the west coast of Ireland. Particularly fine ones are on Achill head (62), southwest of the Bloody Foreland headland (9), Brandon head (160, 171), and Bray head (182, 190).

George island, Alaska, on the west side of Granite cove (C. S., 741).

Point Colorado to cape Haro, Mexico (H. O., 640).

Sixty per cent of the cliffs on the eastern third of the island of Elba (Elba).

A portion of the Adriatic coast of Austria (Austr., 24, IX; 25, IX).

Curzola island (Austr., 34, XVI).

West coast of Brittany (Fr., 57).

Many good examples in Sweden (Swe., 11, 23, 29, 32, 37, 41, 46, 52; 18, 24, 25, 32, 41, 51, 61).

And there are numerous similar youthful cliffs elsewhere.

Minutely Irregular Shoreline. — The minute irregularity of the shoreline of certain regions is a feature to which field study should be directed. As a working hypothesis may be offered the idea that these irregularities are due to minor differences in resistance in beds at the coast. The irregularity in the cases given below does not appear to be due to alternations in the resistance in successive strata.

(Italy, 177, 178).

(Attica, X).

(Denm., Hilderöd).

(Fr., 28, 29), irregular rocky ledges below high water.

The east coast of Öland island (Swe., 17, 22, 38, 30).

The east coast of Gotland (Swe., 23, 31).

South of Warberg (Swe., 18).

Gently Curved Cliffs (Adolescence). — Drakes Bay (Figure 21), California, shows for about one half of its extent transportation alongshore. Many of the cliffs retain youthful irregularities (C. S., 629).

Captains bay, Unalashka island, Alaska (C. S., 821).

Chirikof island, Alaska (C. S., 796).

Similar conditions prevail on either side of Acapulco harbor, Lower California (H. O., 872).

Transportation is seen practically all along the shore from Chipequa point to Ventosa bay, Mexico (H. O., 876).

The cliffs on seventy-five per cent of the central portion and fifty per cent of the western portion of the island of Elba (Elba).

Many portions of the Baltic coast of Germany (Germ., 84, 85, 12, 23, 24, 39, 58, 59, 60, 115, 42, 64, 28, 26, 27, 92, 98).

At many points along the east shore of the Cattegat (Swe., 4, 8, 13, 18).

Straighter Cliffs (Maturity). — When the initial shoreline following depression is all cut back by the sea, the cliff line of the depressed

FIGURE 32. Curved Spit: Dutch Point, Lake Michigan. (Plate XXIX., 13th Ann. Rep. U. S. G. S.)

region is nearly straight, as is also the case with the mature cliff upon an elevated region. Distinction between the two must be sought not in the cliff, but in some other sequential feature. In a depressed region the heads of filled bays may still give witness to the drowning. If a coastal plain region was dissected, then depressed, and then its coast was developed to the middle of the stage called maturity, the evidences of the episode of depression would be lost. The northwestern coast of France is probably an example of a region which has gone through some such history. For other examples of straight coasts consult references on pages 243 and 246.

17. Spits.

A Characteristic of Adolescence. — A spit is formed by currents carrying waste from an attached end into open water, where the unattached point of the spit may be shifted by varying conditions of water motion. Spits are found characteristically along adolescent coasts, and may be found wherever there is transportation alongshore, and are particularly marked at the stage of adolescence.

Straight Spits. — Port Angeles, Washington, is enclosed by Ediz hook, which shows an attempt to form a barb (C. S., 6303, old number 646). This may be considered as an earlier stage of the condition seen in New Dungeness harbor to the east.

Putziger spit (Germ., 27, 47).

A spit has grown northeast into the Zuyder Zee from the dike surrounding Urk island (Holl., 20).

Examples of straight spits occur in the Limfjorden (Denm., Lögstör).

The type example of a broad spit is Skagen point, upon the northern extremity of Jutland (Denm., Hirshals, Skagen). The prevailing motion of currents is indicated by offsets and stream deflection to be toward the point of the spit on the right and from the point on the left. In this example we are able to confirm the indications given by the geographic form, as to the direction of the forming currents, by actual observations. The prevailing current along the west coast of Jutland is from the right, the surface water having been shown to flow from the south toward the point of Skagen spit.* The lines of growth are beautifully shown by the curving strips of marshland; even the artificial ditches follow the same curves as if their location was determined by dune ridges. The direction of growth of this spit has been toward the nearest land on the Swedish coast.

Curved Spits. — Dutch point (Fig. 82), lake Michigan, has grown from right to left, looking from the lake to the shore. Storms from the opposite direction have "turned its end toward the land and the successive recurvements are clearly dis-

* H. Mohn, The North Ocean, Norwegian North Atlantic Expedition, 1876–78, [2,] XVIII. 168, Pl. XLIII.; Danish, Meteorologisk Aarbog, 1880, 1881.

cernible near the apex. The last of these is the greatest; and it is possible that the spit has acquired permanently the form of a hook." *

Hooked Spits. — Cape Lookout † is characterized by a spit projecting from the point of the cusp which has a recurving barbed hook on its left side. The curve of the right side of the spit is continuous with the curve of the right offshore bar, and there is an offset from the right near the point of the cusp proper. On the opposite side of the spit there are three minute offsets, also from the right to the left. The offsets therefore indicate currents flowing in opposite directions upon the two sides of the spit, both moving from the right to the left. The form of the barbed hook is evidence for a current moving from the sea toward the land at this point on the left side of the cusp, because for its extension material must be carried toward the point of the hook from some other locality, and since the hook curves in toward the land and has a smooth contour on the outside and an irregular one on the inside, transportation is inferred along the graded and not the ungraded path. The form of the Lookout recurved spit indicates a current from the land toward the sea on the right and one from the sea toward the land on the left of the cusp.

Capes Obitotchnaïa and Berdianskaïa in the sea of Azov (Atlas Univ., 38) are markedly hooked even on a small scale map.

Messina spit, Sicily, is another hooked spit (Ital. and Sicily, 254).

On the south side of Hjarnö island (Denm., Skanderborg), and southeast of Nyborg (Denm., Nyborg), are two other examples. One forms the harbor of Marstal, aided by artificial breakwaters, another lies five thousand meters to the northwest of the city, and a third hooked spit is about the same distance to the east (Denm , Svendborg).

Another encloses New Dungeness harbor (C. S., 646).

Serpent Spits. — In certain places the currents may be so variable or periodically shifting that the spits do not grow in a straight line or simple curve, but take a serpentine course. In many cases this current irregularity may be due to the form of the bottom, reefs, submerged ridges, etc.

The type example of such spits is that of cape Etolin, Nunivak island, Bering sea (C. S., 896).

Spelmo island has a somewhat similar serpent spit growing northward toward the mainland (Denm., Faaborg).

18. Stages of Development of Various Coasts.

Average Stage. — Taking the criteria as given in this paper as a basis of comparison, the maps of various regions have been studied and compared with any available descriptions; and the regions have then been classified according to the prevailing criteria shown. A few criteria in any region may be in advance or behind the average development of features, and such a region has been classed according to the majority of its features. This classification is not as complete as could be desired,

* G. K. Gilbert, 5th Ann. Rep. U. S. G. S., 96, Pl. IX.

† See page 180.

nor is it free from inaccuracies. The sources of information are in many cases very meagre.

All the reasons for the classification of each example are not discussed; and many of the most important features are omitted, because they already have been considered. Under examples of depression is given some idea of the various kinds of lands which were depressed, and also some hint as to the different stages of development which had been reached before the new cycle was inaugurated.

Uplift: Youth. — The coast of the Argentine Republic (page 162).

Texas (p. 89), and other parts of the Atlantic and Gulf plains.

Maine (C. S. and G. S. sheets), (pages 158, 185, 188).

Corsica (Fr., 261, 263, 265).

Parts of Attica (page 186).

Probably the coast of Brazil from cape Benevento to cape Frio should be here included. The charts show offshore bars enclosing lagoons (H. O., 470, 471), probably following uplift.

Also from cape Santa Marta to Tramandaky bar (H. O., 477).

The southern half of Lower California, Mexico, appears on its western slope to have a coastal plain, described as "low hills and rising plains," with offshore bars enclosing narrow lagoons (H. O., 621).

The western coast of Mexico, east of the gulf of California, also shows a similar coast (H. O., 621 and 622 as far south as San Blas).

A third example in the same general region is seen on the west coast of Guatemala, extending a little on either hand into Mexico and San Salvador (H. O., 931, 932). The detail of bar and lagoon is shown on the chart (H. O., 873). The lack of definite information makes a positive statement in regard to this region unsafe. A study of the maps indicates that they belong in this stage. Mr. J. J. Williams says in regard to this region: "The tertiary clays, gravels, and beds of detritus which cover up so much of the Isthmus along the line of survey, extend on the north side almost to the summit-level, and the base of the hills which lie east and west of it. These deposits being found pretty uniformly spread, even to the depth of thirty feet in some places, as at a point north of the summit-level, and between it and the river Almoloya, are evidences of the slow and tranquil elevation of this portion of the Isthmus above the sea." *

Uplift: Adolescence. — Southern New Jersey (page 184), and other portions of the Atlantic coastal plain.

Uplift: Maturity. — Eastern Italy (page 186). The southeastern and southern coast of the "toe" of Italy (Ital., 246, 247, 255, 263, 264).

The southern coast of Sicily (Ital., and Sicily, 265, 266, 271, 272, 275, 276). The Tertiary strata are considerably deformed and therefore the shoreline is not as straight as in the case of a more simple coastal plain. In a few places along this line the development has hardly reached maturity, as for example west of Pozzallo (276).

Northwestern France (page 241).

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* The Isthmus of Tehuantepec, J. G. Barnard, New York, 1852, 149.

The west coast of Holland from the northernmost outlet of the Rhine to Helder at the inlet to the Zuyder Zee (Atlas Univ. 26; Holl., 14, 19, 24, 25, 30, 37). This is a portion of the confluent delta of the Rhine and adjacent streams.

The coast of Belgium (Atlas Univ., 25; Belg., 4, 5, 11, 12, 19).

Depression : Youth. — Southwest Ireland is a typical example of youthful shore evolution upon a vigorous coast (Ireland, 150, 151, 160, 161, 162, 171, 172, 173, 182, 183, 184, 190, 191, 192, 197, 198, 199, 203, 204). A region of strong relief, with transverse trends, dissected to about early maturity, was deeply drowned and exposed to the strong attack of the open sea. Far up into the bays the waves attack the coast and the offshore currents carry away the waste from the jagged cliffs. Grade is reached only in the bay-bars near the heads of the bays.

The southern coast of Curzola island (Austr., 34, XVI).

The west coast of Central America, San Juan del Sur to gulf of Nicoya (H. O., 1016, details in 1025–1034).

Soledad bay and Santo Tomas anchorage, Lower California (H. O., 1044).

Port Islay, Peru (H. O., 1188).

Brayza island, Austria (Austr., 32, XV).

Meleda island, Austria (Austr., 34, XVII).

The southernmost portion of the Austrian coast, in places becoming adolescent (Austr., 36, XIX ; 37, XX).

Many portions of the coast of Greece (Attica, III, VIII, XVI, XXI, XXII, and XXIII).

The youthful shoreline of the low coast of Saltholm is markedly contrasted with the adolescent shoreline north and south of Copenhagen (Denm., Kjöbenhavn).

The eastern coast of Schleswig (Germ., 7, 13, 14, 23, 24). The development has advanced to adolescence in many of the more exposed portions of this low coast.

The steep eastern coast of Sweden from Hanö Bay northward to a point on the mainland opposite the north end of Öland island (Swe., 6, 10, 11, 12, 17, 22, 29). It is worth notice how slightly the glacial accidents have here modified the forms due to drowning.

The Stockholm district (page 159).

The irregular cliffs of eastern Scotland indicate youthful shore evolution (Scot., 57, 67, 77, 87).* The development has gone a little farther toward adolescence near Rattray head (Scot., 97), but very jagged cliffs are seen to the west of this head (Scot., 95, 96). The north coast of Scotland (Scot., 113, 114, 115, 116) shows almost no transportation alongshore, although several bays have been partly filled.

The west coast of North and South Uist (Scot., 68, 69, 78, 79, 88, 89) shows a nearer approach to adolescent simplification of outline than their irregular eastern coast.

Taken as a whole the western coast of Scotland, where the sea attack is stronger though the rocks are more resistant, is nearer adolescence than the eastern, where the weaker attack of the North sea has not done so much work upon the less metamorphosed rocks. The time since the beginning of the present cycle may not have been the same in the two areas. As the division lines have been drawn in this scheme, this Atlantic coast of Scotland is about on the border between the two stages. Youthful and adolescent features both occur. Two typical areas, from

* See Geikie, Scenery of Scotland, 2d ed., 1887, 56–59.

the northwest and southwest respectively, are given (Scot., 71, 72, 81, 82, 91, 92, 100, 101; 19, 20, 21, 22, 27, 28, 29, 30, 35, 36, 37, 38, 43, 44, 45, 46).

The shores of Kristiania fjord (Nor., 9, A, B, C, D; 10, A, C; 14, B, D).

The Bergen region with structural northwest to southeast trend (Nor., 16, C, D; 22, A, B; 23, A).

Central Norway (page 159).

Southern coast of Finland (Rus., 11, 25).

The eastern shore of the Cattegat northward from Warberg (Swe., 18, 24, 25, 32, 41, 51, 61).

Coast of Chile (H. O., 445, 446, 446ᵃ, 447, 447ᵃ, 38; also Plano Topografico y Geologico de la Republica de Chile, sheet 12).

The California coast near San Francisco (C. S., 5500, 5520, 5521, 5599).

Depression: Adolescence. — The type example of adolescent shore development following depression is in Germany on a coast of moderate relief upon the southern shore of the Baltic (Germ., 1, 3, 8, 15, 16, 25, 26, 27, 28, 29, 30, 43, 44, 45, 46, 47, 48, 49, 50, 65, 66, 70, 71, 72, 73, 92, 93). Beaches occur at the foot of the cliffs, and the cliff lines are gently curving. The transportation of material takes place practically all alongshore, wings have grown out from the headlands, and the bays are nearly all enclosed by bars. Deltas occur at the bay-heads and are growing forward, but the bays are not as yet filled by land waste and sand blown in from the bars. Upon the inside of the bars there are cuspate projections of sand, while nips are seen upon the mainland itself. At a distance of from 3 to 10 kilometers offshore there is a depth of from 20 to 25 meters, which seems to represent the submarine platform. Offsets, overlaps, and stream deflections are not strong in either direction, but show a slight alongshore action toward the east or left, thus indicating a dominant current from the right. This dominance appears to be stronger toward the eastern side: witness the wing growing eastward from Putzig headland, the inlet to Frische bay nearer the northeast end of the bar, and the inlet to Kurische bay crowded way over to the northeast end close to the mainland.

One feature very typical of adolescence which is not well shown along the northern coast of Germany is island-tying. There are several areas, which were possibly isolated portions of the mainland at the beginning of the cycle, that are now completely connected with the mainland by sea and river aggradation, but there are no typical tombolo-tied islands,* so common elsewhere. The reason for the absence of such islands seems to be that this shoreline is one developed upon a drowned coastal plain, not deeply dissected and somewhat masked by glacial aggradation. The writer's interpretation of the late history of this region is that, after the elevation of the Tertiary and Pleistocene strata of the North German plain, the dissection of the land advanced to adolescence. Then followed a moderate depression by which the adolescent valleys were drowned, but the land was not sufficiently dissected to allow the formation of many islands.

Another example is the west coast of Central America, gulf of Nicoya to Burica point (H. O., 1016, 1017).

Blanca and Falsa bays, Lower California (H. O., 1115).

Playa Maria bay to Rosalia point, Lower California (H. O., 1118).

Bay of Avatcha and approaches, Kamchatka (H. O., 54).

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* See page 189.

San Juan Bautista bay, Juan Fernandez island, from Salimas point to Bacalao point (H. O., 1267).

The western coast of Mexico from San Blas to Tehuantepec (H. O., 622, 982, 933; details 876, 915, 936, and 938).

Puget sound (C. S., 6450, 6460).

Transportation occurs along nearly the whole firth of Forth shore (Scot., 32, 38, 40, 41).

The northeast coast of Ireland has entered adolescence (Ireland, 8, 14, 20, 21, 29).

The area of moderate relief in the region of Dublin, from Dundrum bay to Wicklow head (Ireland 60, 61, 70, 71, 81, 82, 92, 102, 112, 121, 130), shows continuous transportation alongshore and other typical features of adolescence.

The eastern coast of Jutland from Skagen to Horsens (Denm., Skagen, Frederickshavn, Aalborg, Mariager, Stavnshoved, Skanderborg). The offsets and river deflections indicate a prevailing current from the left. The shoreline is here much simplified, and for the most part in long swinging curves, but the initial outlines are still seen in the fjorded bays, therefore the shoreline is classed as adolescent approaching maturity.

The east coast of Rügen island (Germ., 42, 64). See also hypsometric map by Dr. R. Credner which shows the simplification of a very irregular shoreline.*

The southeast coast of Möen and Falster (Denm., Moensklint, Vordingborg, Gjedser).† The offsets and stream deflection indicate a prevailing current from the northeast.

Part of the northeast coast of Schleswig-Holstein (Germ., 39, 58, 59, 60).

Southern coast of Sweden (Swe., 1, 2, 3). The streams are deflected to the left, which indicates a dominant current from the right.

The eastern shore of the Cattegat southward from Warberg (Swe., 4, 8, 13, 18).

Portions of the coast of Greece (Attica, VIII, XI, XVII).

The southeast coast of Arabia on the map by S. B. Haines.‡

The coast of Tunis (Tunis, VII, XIV, XXI, etc.).

The northwest shore of the Black sea (Rus., A, 19, 33; Atlas Univ., 88). See page 214.

Depression: Maturity. — The west coast of Italy from Punta Bianca southward to the land-tied island, Massoncello (Ital., 96, 104, 111, 112, 119).

The west coast of the Italian "foot" (Ital., 228, 229, 236).

The western coast of Jutland (Atlas Univ., 30; Denm., Thisted, Lögstör, Lokken, Hirshals, Skagen). A prevailing current from the right is indicated by the offsets.

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* Rügen, Forsch. z. deutsch. Landes- u. Volkskunde, 1898, VII. 373–494.

† See also maps and sketches in Geologie der Insel Möen, by Dr. C. Poggaard, Leipzig, 1852; and for sketches of disturbed strata in cliffs see account by F. Johnstrup, Deutsch. geol. Gesell. Zeit., 1874, XXVI. 533–585.

‡ J. R. G. S., 1845, XV. 104.

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15. TIDAL SCOUR.

16. CLIFFS.

17. SPITS.

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LIST OF ABBREVIATIONS.

Periodicals.

A. A. A. S. = American Association for the Advancement of Science: Salem, Mass.
Am. Geol. = The American Geologist: Minneapolis.
A. J. of S. = The American Journal of Science: New Haven.
Am. Nat. = The American Naturalist: Philadelphia.
Atlan. Mon. = The Atlantic Monthly.
Bull. G. S. A. = Bulletin of the Geological Society of America: Rochester, N. Y.
Bull. Soc. Géog. = Bulletin de la Société de Géographie: Paris.
Bull. U. S. G. S. = Bulletin of the United States Geological Survey: Washington.
C. R. = Comptes Rendus de l'Académie des Sciences: Paris.
C. R. Soc. Géog. = Compte Rendu des Séances de la Société de Géographie: Paris.
Geol. Mag. = London Geological Magazine.
J. A. G. S. = Journal of the American Geographical Society: New York.
Jour. of Geol. = The Journal of Geology: Chicago.
J. R. G. S. = Journal of the Royal Geographical Society: London.
Mem. B. Soc. Nat. Hist. = Memoirs of the Boston Society of Natural History.
Min. Proc. Inst. Civ. Engin. = Minutes of Proceedings of the Institution of Civil Engineers: London.
New Phil. Jour. = New Philosophical Journal: Edinburgh.
Pet. Geog. Mitt. = Petermanns Mitteilungen aus Justus Perthes' geographisches Anstalt: Gotha.
Pet. Geog. Mitt., Erg. = Ditto, Ergänzungs-Heft.
Phil. Trans. = Philosophical Transactions of the Royal Society: London.
Pop. Sci. = Popular Science Monthly: New York.
Proc. Acad. Nat. Sci. Phil. = Proceedings of the Academy of Natural Sciences: Philadelphia.
Proc. B. Soc. Nat. Hist. = Proceedings of the Boston Society of Natural History.
Proc. Geol. Soc. = Proceedings of the Geological Society: London.
P. R. G. S. = Proceedings of the Royal Geographical Society: London.
Q. J. G. S. = Quarterly Journal of the Geological Society: London.
Rep. Brit. A. A. S. = Report of the British Association for the Advancement of Science.
Rev. de Géog. = Revue de Géographie: Paris.
Sci. = Science: New York.
Scot. Geog. Mag. = The Scottish Geographical Magazine: Edinburgh.
Smith. Cont. Kn. = Smithsonian Contributions to Knowledge: Washington.
Trans. Geol. Soc. = Transactions of the Geological Society: London.

U. S. C. G. S. = United States Coast and Geodetic Survey: Washington.
U. S. G. S. = United States Geological Survey: Washington.
Z. d. G. f. E. = Zeitschrift der Gesellschaft für Erdkunde: Berlin.
Z. f. E. = Zeitschrift für Erdkunde: Berlin.

Maps.

Atlas Univ. = Atlas Universel par Vivien de St. Martin: Paris, Hachette & Compagnie. References follow revised numbering of the continuation of the series by Fr. Schrader.
Attica = Karten von Attika, von E. Curtius und J. A. Kaupert, 1 : 25,000: Berlin, 1881–1897.
Austr. = K. u. K. militär-geographisches Institut: Austria, 1 : 75,000.
Belg. = Carte Topographique de la Belgique, 1 : 40,000.
Brit. Ad. = Charts published by Order of the Lords Commissioners of the Admiralty: London, various scales.
C. S. = United States Coast and Geodetic Survey, various scales.
Denm. = Generalstabens Kort over Danmark, 1 : 100,000.
Elba = Carta Geologica dell' Isola d' Elba, 1 : 25,000: Rome, 1884.
Eng. = Ordnance Survey of England, 1 : 63,360.
Fr. = Carte de la France, au Dépôt général de la Guerre, 1 : 80,000.
Geol. Eu. = Carte géologique internationale de l'Europe, 1 : 1,500,000. Beyrich und Hanchecorne, Berlin, 1894.
G. S. = United States Geological Survey, scales, 1 : 62,500, 1 : 125,000.
Germ. = Karte des deutschen Reiches, K. Preuss. Landes-Aufnahme, 1 : 100,000.
Holl. = Topographische en militaire kaarte van het koningrijk Nederlanden, 1 : 50,000.
H. O. = Hydrographic Office, United States Navy, various scales.
Ireland = Ordnance Survey of Ireland, 1 : 63,360.
Ital. = Instituto geografico militare: Italy, 1 : 100,000.
N. J. = Atlas of New Jersey, Geological Survey of New Jersey.
Nor. = Topografisk Kart over Kongeriget Norge, 1 : 100,000.
Rus. = Special Map of European Russia, 1 : 420,000.
Scot. = Ordnance Survey of Scotland, 1 : 63,360.
Sicily = Carta Geologica dell' Isola di Sicilia, 1 : 100,000.
Spain = Memorias de la Comisión del Mapa Geológico de Espana. Mapas, 1 : 400,000.
Spain Bol. = Boletin de la Comisión del Mapa Geológico de Espana. Mapas, 1 : 400,000.
Stieler = Adolf Stieler's Handatlas, Gotha, Justus Perthes, various scales.
Swe. = Generalstabens Karta öfver Sverige, 1 : 100,000.
Swe. Geol. = Sveriges Geologiska Undersökning, 1 : 50,000.
Swiss = Eidgenössisches Militair Archiv, Switzerland.
Tunis = Carte topographique de la Tunisie, Service géographique de l'Armée: France, 1 : 50,000.

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JAPANESE COLLEMBOLA.

By Justus Watson Folsom.

With Three Plates.

JAPANESE COLLEMBOLA. PART II.*

BY JUSTUS WATSON FOLSOM.

Received November 1, 1898. Presented by Samuel H. Scudder, November 23, 1898.

THE interesting collection upon which this paper is based was made by Prof. C. Ishikawa, of the Agricultural College at Komaba, Tokyo, and was most generously given me to study by Professor Packard, to whom my sincere thanks are due. All that has hitherto been published upon the Collembola of Japan is a short article by myself, in which three new species are described. The present paper deals with eleven species, of which six species and one variety are new. In accordance with the wishes of Professor Packard, a series of specimens has been given to the United States National Museum at Washington, D. C., and another to the Museum of Comparative Zoölogy at Cambridge, Mass.

My friend, Dr. C. Shäffer, of Hamburg, has materially assisted my studies by sending identified examples of European Collembola, as well as valuable notes. Mr. Samuel Henshaw has given me many useful suggestions, and freely permitted me to study the collection of the Cambridge Museum.

LIST OF JAPANESE SPECIES.

1. *Aphorura inermis* Tull.
2. *Xenylla longicauda* Folsom.
3. *Achorutes communis* Folsom.
4. *Achorutes gracilis*, n. sp.
5. *Isotoma nitida*, n. sp.
6. *Entomobrya straminea*, n. sp.
7. *Cremastocephalus affinis*, n. sp.
8. *Seira japonica* Folsom.
9. *Tomocerus varius*, n. sp.
10. *Papirius denticulatus*, n. sp.
11. *Sminthurus hortensis* Fitch.
12. *Sminthurus viridis* L. var. *annulatus*, n. var.

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* Part I. was published in Bull Essex Inst., Vol. XXIX., (1897) 1898.

Fam. APHORURIDÆ.

Genus Aphorura MacG.

Aphorura inermis Tull.

(Plate 1, Figs. 1–5.)

1869.	*Lipura inermis*	Tullberg, p. 18.
1868.	" *fimetaria* (L.)	Lubbock, p. 808, Pl. 22, Figs. 27, 28.
1871.	" *inermis*	Tullberg, p. 154.
1872.	" "	" pp. 55, 56.
1873.	" *fimetaria*	Lubbock, pp. 191–193, Pl. 46, Pl. 56, Figs. 24–26.
1873.	" "	Packard, pp. 28, 29.
1878.	" "	Parona, pp. 609, 610.
1890.	" "	Oudemans, p. 90.
1891.	" "	Uzel, p. 75.
1891.	" *inermis*	Schött, p. 24.
1893.	" "	" pp. 88, 89.
1893.	*Aphorura* ———	MacGillivray, p. 318.
1894.	*Lipura inermis*	Lönnberg, p. 165.
1894.	" "	Schött, p. 128.
1895.	" "	Reuter, p. 33.
1896.	" "	Schött, p. 187.
1896.	*Aphorura* "	Schäffer, pp. 161, 163, Taf. 2, Figs. 17–21.
1897.	*Lipura* "	Lie-Pettersen, p. 21.

White (Fig. 1); the contents of the stomach appear as a broad blackish stripe. Eyes absent. Postantennal organ (Figs. 2, 3) elongated, parallel-sided, of eight or nine elements. Pseudocelli of the head ten in number (Fig. 2), of which three lie behind the base of either antenna, and four occupy the posterior border of the head. Antennæ (Fig. 2) shorter than the head, of four segments, related in length as 4 : 5 : 6 : 7; antennal organ (Fig. 4) consisting of a dorso-lateral group of four chitinous, finger-like processes, accompanied by setæ, on the anterior part of the third segment. Body elongated, clothed with short bristles and tuberculated more finely than the head; the number of pseudocelli on the dorsum of each successive segment is, respectively, 0, 4, 4, 6, 6, 6, 6, 4, 0. Legs stout, bristly; superior claws (Fig. 5) stout, curving and tapering uniformly from a broad base, untoothed; inferior claws slightly shorter, slender, gradually attenuating into a fine filament. Ventral tube present; furcula absent. Length, 1.8 mm.

One hundred and forty-two specimens examined, which were collected at Komaba, Tokyo, October 9, 27, and November 14, 1894.

Except for the number of elements in the postantennal organs, the Japanese specimens agree perfectly with North American representatives of the species; the examples from Massachusetts which I used for comparison are of the same lot of which some had been sent to Dr. Schäffer, who pronounced them to be *A. inermis* Tull., and the equivalent of *Lipura fimetaria* (L.) Lubb. Packard's specimens of *L. fimetaria* in the Museum of Comparative Zoölogy are the same species; in fact, Packard himself wrote ('73, p. 24), "It appears that on comparison I can find no difference between European and American specimens of *Lipura fimetaria*." It is at least questionable, however, whether *L. fimetaria* (L.) Lubb. is the Linnæan species.

A. inermis is a widely distributed form, having been recorded from Sweden (Tullberg, Schött), Norway (Lie-Pettersen), Finland (Reuter), Germany (Schäffer), Bohemia (Uzel), Italy (Parona), England (Lubbock), Sumatra (Oudemans), and in North America from Massachusetts (Packard), California (Schött), and Florida (Lönnberg, Schött).

Fam. PODURIDÆ.

Genus Achorutes Templ.

Achorutes communis Folsom.

1898. *Achorutes communis* Folsom, pp. 52, 58, Figs. 1–9.

One hundred and thirty specimens, of all sizes, from Komaba, Tokyo, differ from the types only by having longer and more slender anal spines, in many cases.

Achorutes gracilis, n. sp.

(Plate 1, Figs. 6–13.)

General color, indigo blue (Fig. 6); legs and furcula pale; sternum yellow; the disposition of the hypodermal pigment is shown in Figure 7. Head clothed with stiff setæ; eyes eight on either side (Fig. 8), upon black patches; postantennal organ (Fig. 9) of four elements. Antennæ subequal to the head in length, with long bristles and with segments related in length as 3 : 4 : 4 : 6. Body cylindrical-ovate in dorsal aspect (Fig. 6), and sparsely clothed with short reclinate setæ (Fig. 10). Legs stout, basally spotted with blue; superior claws (Fig. 11) uniformly ta-

pering and curving, unidentate one third from the apex; inferior claws half as long, lunate, acuminate; tenent hairs, two on the fore feet and three on the others. Dentes stout, slightly tapering, with stout reclinate satæ and a few extra long bristles; mucrones a third as long as the dentes, in form as represented in Figure 12. Anal spines (Fig. 13) two, small and conical. Length, 1.5 mm.

Described from twenty-four types, from Yanaka, Tokyo, November 18, 1894.

This species closely approaches the European *A. purpurascens* Lubb., as well as *A. theelii* Tull. of Nova Zembla, both of which species I have received from Dr. Schäffer; from these *A. gracilis* is distinguished especially by the form of the mucrones, together with the coloration.

Fam. ENTOMOBRYIDÆ.

Genus Isotoma Bourl.

Isotoma nitida, n. sp.

(Plate 1, Figs. 14–18.)

Bluish gray, with a slight greenish tinge; antennæ darker; sides mottled with pale spots; sternum pale. Head, body, and appendages clothed with short dense bristles (Fig. 14); genæ gibbous. Eyes (Figs. 15, 16) eight on either side, upon black patches; postantennal organ absent. Antennæ two fifths as long as the body, stout, with segments related in length as 2 : 4 : 4 : 5, and with the last three segments petiolate. Superior claws (Fig. 17) broad basally, slightly curved, untoothed, with two filiform pseudonychia; inferior claws broadly lanceolate, without teeth; tenent hairs absent. Furcula slender, exceeding the ventral tube, with segments related as 4 : 16 : 1; mucrones (Fig. 18) four-toothed. Length, 1.4 mm.

Described from seventy-two types, of which seven were collected at Komaba, Tokyo, November 16, 1894, and the remainder at Miyagi, Boshyu, November 9, 1895.

This species is, upon the whole, most nearly allied to *I. palustris* Müll., especially in the form of the mucrones (cf. Schött '93, Taf. 6, Fig. 5).

I find no species of *Isotoma*, except that now described, which possesses filiform pseudonychia.

Genus Entomobrya Rond.

Entomobrya straminea, n. sp.

(Plate 2, Figs. 19–23.)

Pale straw yellow throughout. Head, body, and appendages densely clothed with barbellate bristles; the vertex and basal antennal segment bear also stout, clavate setæ (Figs. 19, 20). Eyes three on either side, black, arranged as in Figure 21. Antennæ almost half as long as the body, segments cylindrical, related in length nearly as 1 : 2 : 2 : 3. The body segments, measured along the median dorsal line, are related as 4 : 17 : 12 : 8 : 11 : 11 : 31 : 5 : 3; a cluster of clavate setæ arises from the anterior border of the mesonotum, and a similar dorsal cluster occurs upon each succeeding segment. Legs slender; superior claws (Fig. 22) almost straight, tapering to a sharp point, in lateral aspect showing a small tooth on the outer margin and two on the inner margin; one of the latter is comparatively small, situated near the middle, and overhung by the greatly developed second, or basal tooth; inferior claws over half as long as the others, straight, broadly linear, acuminate, bearing on the outer margin a broad, acute, hyaline lamella; a single stout but unknobbed tenent hair is present. Furcula with segments related as 28 : 49 : 3; mucrones (Fig. 23) broadly falcate, with a prominent erect tooth near the middle and surrounded by three or four stout barbellate bristles which project from the dentes. Length, 1.9 mm.

Seven types, from Komaba, Tokyo, November 16, 1894.

E. straminea agrees with *E. sexoculata* Schött ('96, pp. 180, 181, Pl. 17, Figs. 30–32) in the number of eyes, but differs in the formation of the claws and mucrones, as well as in other respects. It also bears much resemblance to *Sinella höfti* Schäffer ('96, pp. 192, 193, Taf. 4, Figs. 103–105). For reasons already urged by Schött ('91, p. 20, '96, p. 180), I follow that author in uniting the genus *Sinella* with *Entomobrya*.

Genus Cremastocephalus Schött.

Cremastocephalus affinis, n. sp.

(Plate 2, Figs. 24–27.)

Color, chrome yellow; the lateral borders of segments two to six inclusive, the posterior borders of the last two abdominal segments and

the apex of each antennal segment are frequently dark purple; the antennæ, legs, and furcula are pale yellow. The head hangs down (Fig. 24), is elongated, and clothed with numerous proclinate bristles interspersed with extra long, slender, erect bristles; similar long bristles occur also on the body, antennæ, legs, and furcula. Eyes eight on either side (Fig. 25), arranged in two longitudinal rows, on black patches. Antennæ one fourth longer than the body, bristly, with segments cylindrical or slightly dilated and related to each other in length as 25 : 31 : 27 : 35. The body (Fig. 24) is elongate-cylindrical, clothed with reclinate bristles and scaleless; its segments, measured along the median dorsal line, are related as 2 : 12 : 8 : 6 : 7 : 2 : 34 : 4 : 4. The thorax curves downward; the mesonotum almost covers the prothorax and bears clavate bristles on its anterior border. Legs long, slender, and bristly; superior claws (Fig. 26) stout, but little curved, with a tooth on the inner margin, one third from the apex, and a second tooth near the base; inferior claws half as long as the others, broad, with acuminate apex, convex outer margin and a single tooth, borne upon an obtuse angle at the middle of the inner margin; a single tenent hair is present which gradually expands to a broad truncate apex. Furcula five eighths as long as the body and bristly; manubrium cylindrical, slightly shorter than the dentes; dentes gradually tapering, each bearing a large oval scale near the apex (Fig. 27); mucrones oblong, somewhat curved, with three terminal lobes, which are subequal, rounded, and surrounded by barbellate bristles projecting from the dentes. Length, 2 mm.

Described from seven types, collected at Komaba, Tokyo, October 25, 1894.

This curious form is closely related to the Mexican *Cremastocephalus trilobatus* Schött ('96, pp. 175–178, Plate 16, Figs. 20–23, Plate 17, Figs. 25, 26), which has hitherto been the only representative of its genus. The specific distinctness of the two species is evident when my figures are compared with those of Schött; the chief differences exist in coloration and the form of claws and mucrones; the dental scale is elliptical in *trilobatus*, but oval in the species now described. I may mention that, although Schött states that the upper claw of *trilobatus* is "provided with two teeth," there are three represented in his figure.

Genus SEIRA Lubb.

Seira japonica Folsom.

1898. *Seira japonica* Folsom, pp. 55, 56, Figs. 15–18.

Many of Dr. Ishikawa's specimens differ from my types by being larger, attaining a length of 3 mm. The antennal segments are more slender, are related to each other nearly as 3 : 5 : 4.5 : 6, and are purple throughout. Clavate hairs are few in number and the scales have disappeared. The second abdominal segment is usually yellow; the mesonotum is laterally bordered with blackish blue and occasionally each side of the head bears a stripe of that color. A single example is yellow throughout, excepting the antennæ, lateral borders of meso- and metanotum and the posterior border of the fifth abdominal segment, all of which are purple. In all other respects the specimens agree perfectly with the types, which are manifestly younger individuals.

Sixteen specimens, large and small, were taken at Komaba, Tokyo, October 27 and November 16, 1894. I omitted to mention in my previous paper that the types are dated June 24, 1897.

Genus TOMOCERUS Nic.

Tomocerus varius, n. sp.

(Plate 2, Figs. 28–30, Plate 3, Figs. 31, 32.)

Color with scales, plumbeous; without them, dull yellow. Eyes (Fig. 28) six on either side, on black patches. Antennæ almost as long as the body, with purple segments, related in length as 3 : 4 : 27 : 5. From under the anterior margin of the mesonotum project many stout stiff setæ (Fig. 29). Superior claws (Fig. 30) nearly straight, rather stout, with from two to five teeth which successively become more obscure toward the apex of each claw; in the few specimens at command, the fore claws bear two or three teeth, the mid claws from two to five, and the hind claws two; the right and left claws of the same pair of feet often differ in the number of teeth. The inferior claws are a little more than half as long as the others, broadly lanceolate and unidentate. A single tenent hair is present. Furcula seven tenths the length of the body, with segments related nearly as 3 : 4.5 : 1. The dental spines (Fig. 31)

are simple and vary in number from eight to ten; the proximal spines are smallest and the two most distal are largest. Each mucro (Fig. 32) bears a single blunt tooth near the middle. Length, 2.5 mm.

Described from three types, collected at Komaba, Tokyo, November 16, 1894, and Oji, Tokyo, November 18, 1894. These had unfortunately dried and shrivelled.

This species is intermediate between *T. minutus* Tull. ('76, p. 32, Taf. 8, Figs. 9, 10) which has 2–3 teeth on the superior claws and 10–11 dental spines, and *T. arcticus* Schött ('93, pp. 43, 44, Taf. 3, Figs. 8, 9) which possesses 4–5 teeth and 7–8 spines.

Fam. SMINTHURIDÆ.

Genus Papirius Lubb.

Papirius denticulatus, n. sp.

(Plate 3, Figs. 33–36.)

Pale chrome yellow, with purple markings (Fig. 33). Head sparsely clothed with stout, stiff setæ; eyes upon black patches. Antennæ purple, three fourths as long as the body, with segments related nearly as 1 : 4 : 7 : 2; third segment with at least nine distal subsegments and dilated apex; terminal segment lanceolate in outline, with the basal half composed of four subsegments. Legs yellow, banded with purple, with stout bristles; superior claws (Fig. 34) slender, nearly straight, the outer margin unidentate one third from the apex, both inner margins bidentate; inferior claws (Fig. 34) over half as long, with acute apex. almost parallel sides, long, knobbed, subapical hair, and two unequal, perpendicular teeth on the rounded basal portion of the inner margin; the smaller tooth is occasionally absent; a single, slender, unknobbed tenent hair is present. Abdomen elongate-ovate, sparsely clothed with short, stiff setæ, which become longer and numerous posteriorly. Coloration as shown in Figure 33; two broad paramedian stripes occur upon the anterior half of the dorsum; several oblique wedge-shaped bands extend upward and backward from either side; a median U-shaped mark is conspicuous on the posterior part of the dorsum. Furcula yellow, bristly, with segments related as 2 : 4 : 1; manubrium broadly oblong in dorsal aspect; dentes slender, with long, stout, lateral bristles (Fig. 33) which become barbellate toward the apices of the dentes (Figs.

35, 36); mucrones (Fig. 35) oblong-lanceolate, serrate upon both edges. Length, 2 mm.

Three types, from Komaba, Tokyo, November 16, 1894.

P. denticulatus most nearly approaches the North American *P. marmoratus* Pack. ('73, p. 42), of which I have examined the types and with which I am inclined to regard *P. maculosus* Schött ('91, pp. 14, 15, Taf. 3, Figs. 1–3) as synonymous.

Genus Sminthurus Latr.

Sminthurus hortensis Fitch.

(Plate 3, Figs. 37–40.)

1863.	*Smynthurus hortensis*	Fitch, pp. 668–673, Figs.
1841.	—— ——	Harris, p. 125.
1842.	—— ——	" "
1844.	*Smynthurus* sp.	" Fig.
1969.	" [*cucumeris*]	" p. 362.
1871.	*Sminthurus pruinosus*	Tullberg, p. 145.
1872.	" "	" p. 31, Taf. 3, Figs. 13, 14.
1878.	*Smynthurus quadrisignatus*	Packard, p. 44.
1876.	*Sminthurus lineatus*	Reuter, p. 83.
1891.	*Smynthurus hortensis*	MacGillivray, p. 271.
1891.	" *frontalis*	Uzel, p. 37, Taf. 1, Fig. 3, Taf. 2, Figs. 3–5.
1893.	*Sminthurus pruinosus*	Schött, pp. 28, 29, Taf. 2, Figs. 13–16.
1895.	" "	Reuter, pp. 10–12.
1897.	" "	Schäffer, p. 26.
1897.	*Smynthurus albamaculata*	Harvey, pp. 124–126, Figs. 1–5.
1898.	*Sminthurus pruinosus*	Scherbakow, p. 60.

General color dark purple, spotted with pale yellow; antennæ, legs, and furcula paler purple. Head densely clothed with short proclinate setæ. Eyes (Fig. 37) upon large black patches, broadly surrounded with pale yellow; vertex yellow; genæ with several circular yellow spots. Antennæ over half as long as the body, with segments related as 2 : 4 : 17 : 15; terminal segment composed of seven subsegments: the apical two thirds of the terminal segment (Fig. 38) consists of six subsegments, of which five are subglobose, while the last is elongate-conical and itself represents three subsegments, which however are not distinct as such. Legs bristly; segments darker apically; superior claws (Fig. 39) tapering, slightly curved, unidentate near the middle of the inner edge; inferior claws three fifths as long, entire, apex acuminate,

outer margin straight, inner margin roundly dilated near the base; tenent hairs two or three, clavate. Coloration rather variable; dorsum marked anteriorly with transverse rows of pale yellow circular spots (Fig. 37); sides of abdomen with many regular rows of minute, circular, yellow spots; sternum posteriorly yellow; body well clothed with bristles, which are short and reclinate, except upon the posterior segments, where they become longer and more numerous. Furcula long and stout; dentes scarcely tapering; mucrones (Fig. 40) almost one third as long as the dentes, oblong-lanceolate, with rounded apex. Length, 1.2 mm.

Two specimens with no locality given.

The Japanese examples agree satisfactorily with North American representatives of *S. hortensis;* in fact, I found some of our specimens which match them quite closely in coloration. A study of Packard's types leaves no doubt that *quadrisignatus* Pack. is a synonym of *hortensis* Fitch. Professor Harvey kindly sent me numerous specimens of his *albamaculata*, which also prove to be *hortensis;* he regards the last antennal segment as being composed of nine subsegments, evidently considering the last subsegment as three. The identity of the European *pruinosus* Tull. with the American *hortensis* was called to my attention by Dr. Shäffer, to whom I had sent examples of our species, and he has since sent me ten South American specimens of the same form.

S. hortensis has been found in various parts of Europe: in Sweden (Tullberg), Finland (Reuter), Russia (Scherbakow), and Bohemia (Uzel). In the United States it is recorded from New York (Fitch), Maine (Packard, Harvey), Massachusetts (Harris), and Ohio (MacGillivray). Finally, it is reported from subantarctic America (Schäffer).

Sminthurus viridis Linn., var. *annulatus*, n. var.

(Plate 3, Figs. 41–43.)

1758.	*Podura viridis*	Linnæus, p. 608.
1762.	" "	Geoffroy, p. 607.
1781.	" "	Schrank.
1793.	" "	Fabricius, p. 65.
1804.	*Smynthurus viridis*	Latreille, p. 82.
1806.	" "	" p. 166.
1835.	" "	Lacordaire et Boisduval, p. 115.
1835.	" "	Templeton, p. 97, Pl. 12, Fig. 7.
1839.	" "	Burmeister, p. 451.
1841.	" "	Nicolet, p. 82, Pl. 9, Fig. 9.
1842.	" "	Bourlet.

1842.	*Smynthurus viridis*	Lucas, p. 567.
1844.	" "	Gervais, p. 401.
1868.	" "	Lubbock, pp. 295, 296, Pl. 21, Figs. 1–3.
1871.	*Sminthurus* " vars. *cinereoviridis, nigromaculata*	Tullberg, pp. 144, 145.
1872.	*Sminthurus viridis*	Tullberg, p. 80, Taf. 2., Figs. 16–20, Taf. 3, Figs. 1–5.
1873.	*Smynthurus* "	Lubbock, pp. 100, 101, Pl. 1, Pl. 55, Figs. 1–4.
1876.	*Sminthurus* "	Reuter, p. 79.
1876.	" "	Tullberg, p. 80.
1883.	*Smynthurus* "	Tömösváry, pp. 37, 38.
1888.	" "	Dalla Torre, p. 149.
1891.	*Sminthurus viridis* var. *tripunctatus*	Reuter, p. 227.
1891.	*Sminthurus viridis,*	Uzel, pp. 34, 35.
1893.	" " vars. *speciosus, dorsovittatus*	Schött, pp. 22–24, Taf. 1, Figs. 1–5.
1895.	*Sminthurus viridis,*	Parona, p. 696.
1895.	" " var. *infuscatus*	Reuter, pp. 9–10.
1896.	*Sminthurus viridis,* var. *multipunctata*	Schäffer, pp. 209, 210, Taf. 4, Figs. 122, 123.
1897.	*Sminthurus viridis*	Poppe und Schäffer, p. 271.
1897.	" "	Lie-Pettersen, p. 8.
1898.	" " var. *lineata*	Scherbakow, pp. 60, 65.

Pale yellow, spotted with blackish purple (Fig. 41); most of the spots are approximately ring-like, being polygonal with pale centres; one individual is pale yellow throughout, except for faint purple spots on the posterior part of the abdomen. Head densely clothed with proclinate bristles. Eyes upon black patches. Antennæ three fifths as long as the body, yellow basally, purplish apically, with segments related as 1 : 4 : 6 : 13; terminal segment composed of about seventeen subsegments. Body clothed with long reclinate bristles, numerous upon the anal tubercle. A median dorsal purple streak occurs on the anterior half of the body. Legs pale yellow, with long setæ. Superior claws (Fig. 42) stout, broad, slightly curved, mucronate at apex and unidentate on the inside, two fifths from the apex; inferior claws over half as long, broadly triangular, with a subapical hair and a single tooth upon the inner, rounded margin; tenent hair single, slender, and unknobbed. Furcula pale yellow with long setæ; mucrones (Fig. 43) elliptical, with entire margins. Length, 2 mm.

Described from two types, found at Komaba, Tokyo, November 16, 1894.

Upon comparing the Japanese variety with several examples of *S. viridis* L. var. *cinereoviridis* Tull., which Dr. Schäffer gave me, I find but few structural differences; the European variety has more slender mucrones and is clothed with longer bristles.

S. viridis is extremely variable in coloration and the present variety is the ninth to receive a name. The species ranges throughout Europe, having been recorded from Sweden (Tullberg), Norway (Lie-Pettersen), Finland (Reuter), Russia (Scherbakow), Nova Zembla (Tullberg), France (Bourlet, Geoffroy), Switzerland (Nicolet), Germany (Reuter, Schäffer), Bohemia (Uzel), Tyrol (Dalla Torre), Hungary (Tömösváry), Italy (Parona), England (Lubbock,) and Ireland (Templeton). Outside of Europe, it is known from Tunis (Parona), Siberia (Reuter), and South America (Parona).

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PLATE 1.

Fig. 1.	*Aphorura inermis*, Tull.			× 26.
Fig. 2.	"	"	"	Dorsal aspect of head, × 58.
Fig. 3.	"	"	"	Postantennal organ, × 540.
Fig. 4.	"	"	"	Left antennal organ, × 424.
Fig. 5.	"	"	"	Left aspect of right hind foot, × 424.
Fig. 6.	*Achorutes gracilis*, n. sp.			× 26.
Fig. 7.	"	"	"	Plan of coloration, × 269.
Fig. 8.	"	"	"	Eyes of right side, × 352.
Fig. 9.	"	"	"	Postantennal organ of left side, × 424.
Fig. 10.	"	"	"	Clothing of an abdominal segment, × 269.
Fig. 11.	"	"	"	Left aspect of right hind foot, × 424.
Fig. 12.	"	"	"	Left aspect of left mucro, × 424.
Fig. 13.	"	"	"	Left aspect of left anal spine, × 424.
Fig. 14.	*Isotoma nitida*, n. sp.			× 26.
Fig. 15.	"	"	"	Eyes of right side, × 352.
Fig. 16.	"	"	"	Eyes of right side, diagrammatically, × 352.
Fig. 17.	"	"	"	Right aspect of right hind foot, × 424.
Fig. 18.	"	"	"	Right aspect of left mucro, × 540.

PLATE I.

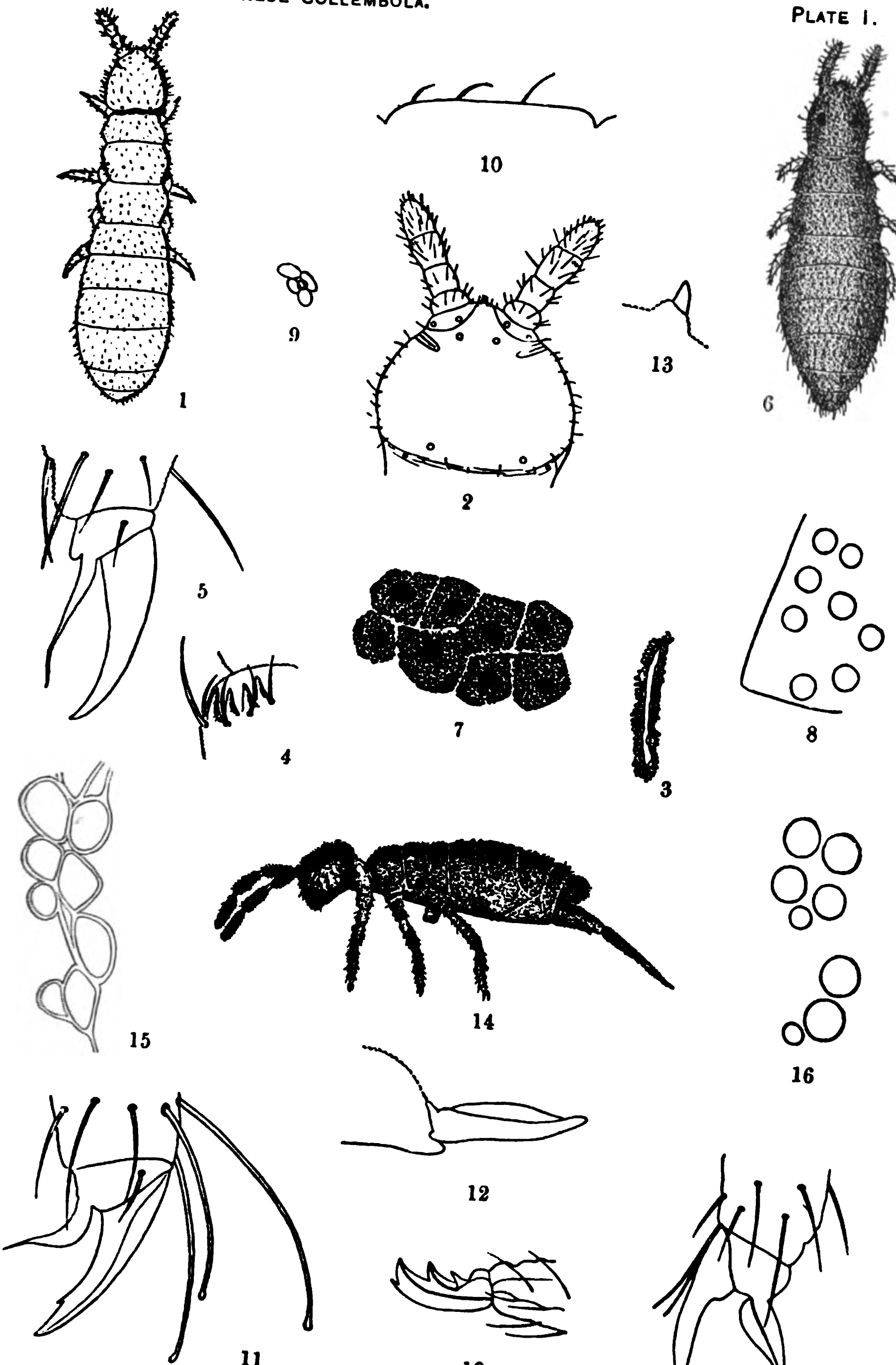

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PLATE 2.

Fig. 19.	*Entomobrya straminea*, n. sp.	× 96.
Fig. 20.	" " "	Bristle from head, × 424.
Fig. 21.	" " "	Eyes of left side, × 352.
Fig. 22.	" " "	Left aspect of left fore foot, × 540.
Fig. 23.	" " "	Left aspect of left mucro, × 540.
Fig. 24.	*Cremastocephalus affinis*, n. sp.	× 44.
Fig. 25.	" " "	Eyes of left side, × 269.
Fig. 26.	" " "	Left aspect of right fore foot, × 540.
Fig. 27.	" " "	Mucro, × 540.
Fig. 28.	*Tomocerus varius*, n. sp.	Eyes of left side, × 124.
Fig. 29.	" " "	Bristles of mesonotum, × 424.
Fig. 30.	" " "	Right aspect of right mid foot, × 424.

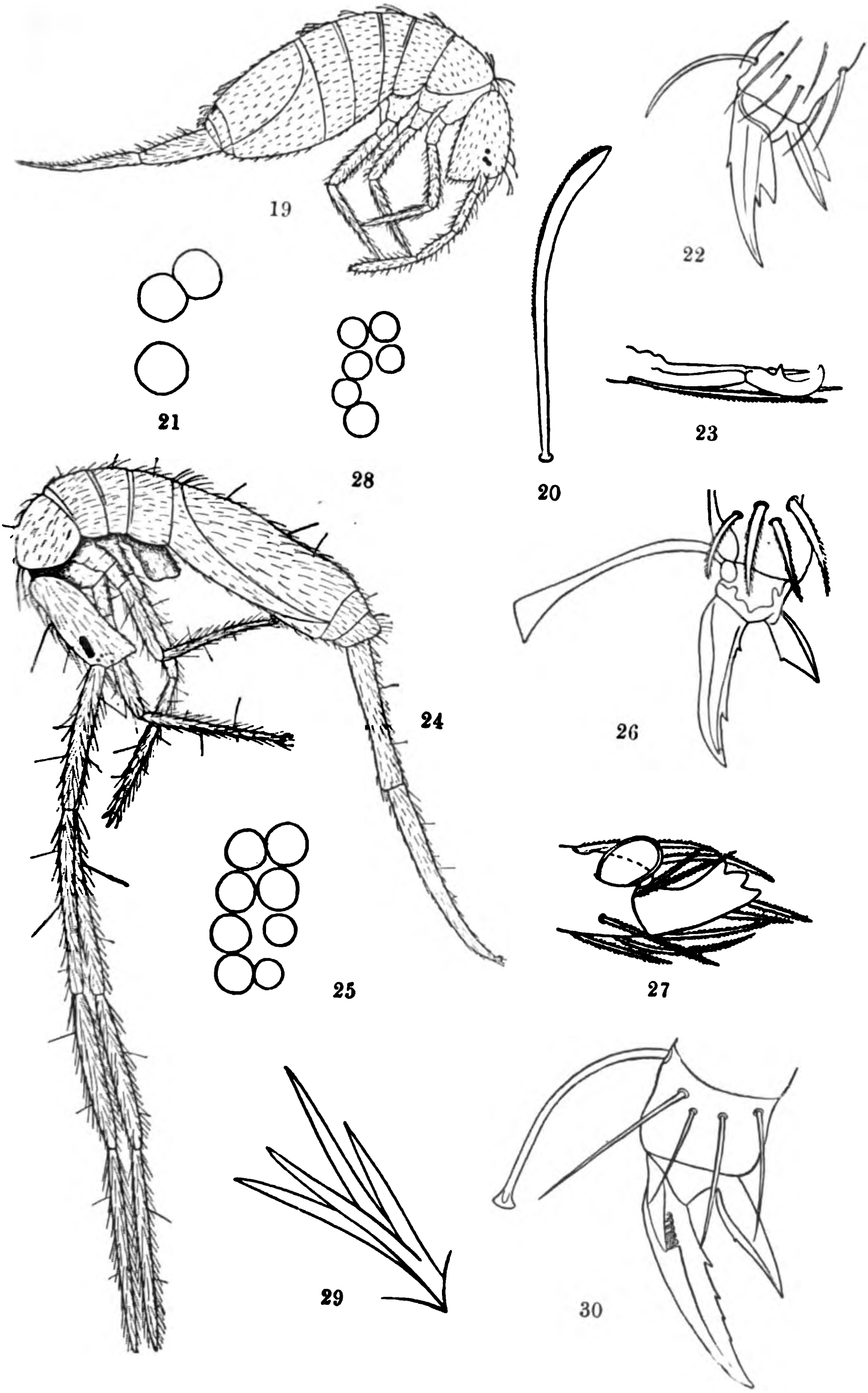

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PLATE 3.

Fig. 31.	*Tomocerus varius*, n. sp.	Dental spines, × 65.
Fig. 32.	" " "	Right aspect of right mucro, × 269.
Fig. 33.	*Papirius denticulatus*, n. sp.	× 26.
Fig. 34.	" " "	Right aspect of right mid foot, × 269.
Fig. 35.	" " "	Left aspect of left mucro, × 136.
Fig. 36.	" " "	Bristle from dens, × 605.
Fig. 37.	*Sminthurus hortensis*, Fitch.	× 68.
Fig. 38.	" " "	Terminal antennal segment, × 65.
Fig. 39.	" " "	Left aspect of left mid foot, × 605.
Fig. 40.	" " "	Mucro, × 269.
Fig. 41.	*Sminthurus viridis*, var. *annulatus*, n. var.	× 26.
Fig. 42.	" " " " "	Right aspect of right hind foot, × 269.
Fig. 43.	" " " " "	Left aspect of left mucro, × 136.

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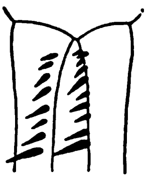

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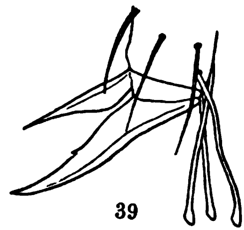

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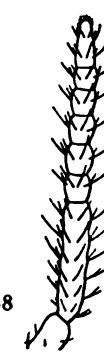

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

THE USE OF THE TRANSITION TEMPERATURES OF COMPLEX SYSTEMS AS FIXED POINTS IN THERMOMETRY.

By Theodore William Richards and Jesse Briggs Churchill.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

THE USE OF THE TRANSITION TEMPERATURES OF COMPLEX SYSTEMS AS FIXED POINTS IN THERMOMETRY.

BY THEODORE WILLIAM RICHARDS AND JESSE BRIGGS CHURCHILL.

Received November 14, 1898. Presented November 28, 1898.

IN a brief paper upon the transition temperature of sodic sulphate,* we have recently shown that this non-variant point is capable of being reproduced in practice with great certainty, and that it is therefore admirably suited for use as a standard of reference in thermometry. We pointed out the fact that many other systems composed of two or more components might answer equally well, and declared our intention of fixing as many points as possible in order to simplify the accurate measurement of temperature. The subsequent appearance of a hastily written note by Messrs. Meyerhoffer and Saunders,† claiming for themselves a part of this scheme, has prompted the present paper, which has as its object a more detailed statement of the plan.

It is obvious that, while any number of components might be employed simultaneously for this service, the simpler systems will be on the whole the most useful. Water is so omnipresent as to be difficult to exclude from any kind of experiment, hence the investigator is almost forced to adopt it as one of the components. The choice is then of the other material or materials, and the first step was obviously to study all common substances with a view to discover the probable usefulness of the transition temperatures of their aqueous crystals. If a complete temperature scale could not be built up from such simple data it would obviously become necessary to investigate quintuple points, of which a very great number could be devised. This additional complication could not but be regretted, however; for it involves the necessity of preparing two salts instead of one in a pure state, it renders less easy the use of

* American Journal of Science, VI. 201 (1898); also Zeitschr. phys. Chem., XXVI. 690.

† Zeitschr. phys. Chem., XXVII. 367, October, 1898.

the same material over and over again, and it introduces a complication which might seriously retard the speed of attaining equilibrium, and hence the constancy of the desired point.

After studying with care the published records of all the field of inorganic chemistry, about two dozen salts were selected as probably suitable for the work in hand. Of these magnesic and nickelous sulphates, calcic and nickelous nitrates, nickelous chloride and borax were rejected as being too inconstant in their indications. The lack of constancy was due sometimes to the smallness of the latent heat of transition, and sometimes to a superabundance of crystalline hydrates. On the other hand, at least eight of the new salts gave results comparable in certainty with those given by the ever trustworthy Glauber's salt. These salts are given in the table below.

TRANSITION TEMPERATURES OF NINE SALTS.

Salt.	By Mercury Thermometer.	By Hydrogen Thermometer.
Sodic Chromate, $Na_2CrO_4 . 10H_2O$ . .	19.7	19.6
Sodic Sulphate, $Na_2SO_4 . 10H_2O$ . . .	32.484	32.379
Sodic Carbonate, $Na_2CO_3 . 10H_2O$ . .	35.2	35.1
Sodic Thiosulphate, $Na_2S_2O_3 . 5H_2O$.	48.1	48.0
Sodic Bromide, $NaBr . 2H_2O$	50.8	50.7
Manganous Chloride, $MnCl_2 . 4H_2O$ . .	57.9	57.8
Strontic Chloride, $SrCl . 6H_2O$ . . .	61.1	61.0
Sodic Phosphate, $Na_3PO_4 . 12H_2O$ . .	73.5	73.4
Baric Hydroxide, $Ba(OH)_2 . 8H_2O$ . .	78.0	77.9

The temperatures given above are only approximations, and are subject to future revision; at this stage of the work our effort has been only to determine if the points were constant, and not to fix their absolute value. Besides these nine, several other salts promise well. Baric hydrate, given above, was our first trial of three components, for the carbonate was naturally allowed to be present. The study of such quintuple points has now been interrupted by Messrs. Meyerhoffer and Saunders's claim.

These gentlemen studied in a very hasty fashion the transition temperature of Glauber's salt in the presence of an excess of common salt. Although theoretically sound, such a system labors under a serious practical disadvantage; for the addition of heat to it means the dissolving of common salt as well as the melting of crystallized sodic sulphate and the depositing of anhydrous material. The first of these processes is obviously less speedy than the others, and must surely occupy appreciable time even if the solid is finely powdered. Such a "lag" inevitably affects the temperature; our own experience with this mixture as well as with other similar ones supports this inference, and is anything but reassuring. Indeed, we found that Glauber's salt itself did not give absolutely accurate results if it was allowed to "freeze" instead of to "melt," for a similar reason.

We agree with Messrs. Meyerhoffer and Saunders as to the great desirability of uniting upon some normal temperature for the graduating of flasks, etc., but we cannot conclude with them that 18° is the best temperature. In America the steam-heated winters and sun-heated summers raise the average temperature of our laboratories at least to 20°, and indeed this temperature is more comfortable than 18° unless one is performing active manual labor. Hence at Harvard we have settled upon 20° as the normal room temperature. Sodic chromate (19.6°) clearly gives us very nearly the standard of reference which we desire. In determining the specific gravities of liquids, a temperature *above* that of the room is preferable to one *below*, — for the expansion of the liquid during the drying of the exterior of the pycnometer is otherwise apt to be troublesome, hence 18° is not suitable for this purpose. The authors before mentioned suggest the use of a bath of mixed salts as a means of keeping the temperature constant during determinations of electrolytic conductivity; but it should be pointed out that in such work the neighborhood of a very large amount of a good electrolyte is necessarily risky, except in the best of hands. This is especially the case when the substance effloresces to form a fine powder, easily wafted around by currents of air. In short, while for some work with closed vessels demanding the greatest accuracy such a bath may be invaluable, the Ostwald thermostat is the safest and most convenient appliance for preserving a constant temperature in the laboratory. The baths of "melting" crystals will find their greatest use in the standardizing of thermometers at fixed points; and these thermometers will continue to serve as the most handy means of attaining and registering any desired temperature. It is obvious that if a thermometer is standardized under exactly the

conditions imposed upon it during its use, the correction for the cool column projecting into the air may be omitted. This correction, by the way, may account for the fact that Meyerhoffer and Saunders found the transition temperature of sodic sulphate to be only 32.35° * instead of 32.38.°

We are much pleased that the idea should have been grasped with such eagerness in the laboratory of Professor van't Hoff, for no better proof could be found of its unquestionable utility. We feel too that constants of this sort, like atomic weights, should be studied by more than one set of investigators, and that they should be finally investigated with the utmost care in the Bureau Internationale des Poids et des Mesures, and the Reichsanstalt; hence we are glad to accord to Messrs. Meyerhoffer and Saunders the right which they demand to investigate quintuple points involving sodic sulphate or sodic carbonate. At the same time, we feel that our undoubted priority (our preliminary paper having been finished early in June) allows us to study any desired portion of this field; and for the present, feeling that the simpler systems are the better ones, we shall investigate primarily the salts named above.

CAMBRIDGE, November 14, 1898.

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* By a clerical error, Rimbach's table for this correction was stated in our last paper to be on page 143 of Landolt and Börnstein's Tables (1894). It is really on page 95.

Proceedings of the American Academy of Arts and Sciences.

VOL. XXXIV. NO. 11. — FEBRUARY, 1899.

ON THE THERMAL CONDUCTIVITY OF CAST IRON.

BY E. H. HALL AND C. H. AYRES.

WITH TWO PLATES.

INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATION FROM THE RUMFORD FUND.

ON THE THERMAL CONDUCTIVITY OF CAST IRON.

By E. H. Hall and C. H. Ayres.

Presented October 12, 1898. Received December 6, 1898.

Two or three years ago an article entitled "On the Thermal Conductivity of Mild Steel" was published by one of the authors * of the present paper. The method described at length in that article made use of a disk of soft steel, about 0.3 cm. thick and about 10 cm. in diameter, coated on each face with an electrolytic deposit of copper about 0.05 cm. thick. Thin copper wires attached electrolytically to these copper coatings led to a sensitive galvanometer, the deflections of which depended upon the thermo-electromotive force of the couple made by the steel of the disk and the copper of its coverings, and indicated the difference of temperature existing between the two faces of the steel itself.

Water of a known temperature was made to flow across one copper face of the disk and water eight or ten degrees warmer across the other copper face. The water delivery of one stream was measured, and its change of temperature between entering and leaving the vessel containing the disk was determined by means of two copper and German silver thermo-electric junctions.

The apparatus containing the disk was surrounded by a water jacket having a temperature near that of the disk, so that the radiation to or from the exposed convex surface of the disk could be neglected.

This hasty review shows that, if all the measurements indicated were correctly made, the thermal conductivity could be found by a simple calculation based on the data afforded by the experiments. In fact, the experiments described in the article under discussion left something to be desired; for they showed that different parts of the same face of the disk were not at the same temperature, and the process of calculation necessary to deduce from the observations the mean difference of temperature of the two faces of the disk was laborious, and perhaps to the casual reader not entirely convincing. This difficulty and the desirability of certain changes in the apparatus used were recognized in the article itself.

* E. H. Hall, These Proceedings, Vol. XXXI. p. 271, 1896.

The authors of the present paper have used the same method, applying it to measure the thermal conductivity of a certain grade of cast iron; but they have employed a thicker disk and thicker layers of copper. The result of these changes has been to produce such uniformity of temperature over each face of the disk, that calculation of the mean difference of temperature between the two faces of the disk has become an exceedingly simple matter.

The Iron Used.

The disk was made from a slab of cast iron the origin and description of which are well set forth in the following extract from a letter written by Mr. A. C. Colby, the metallurgical engineer of the Bethlehem Iron Company: —

"Dear Sir, — In response to the instructions contained in your letter of the 30th ultimo, I send to-day . . . the casting which has been made at these works, and for which no charge will be made to you. I selected a high silicon iron so as to make the casting free from any chill, and it is smooth as can be obtained in a sand lined mould, and, I think, very close to the dimensions you desire, namely, 12″ × 4″ × 1″.

"In the following composition of the iron entering into this casting, the sulphur and silicon determinations were made on a gate of the casting. The other determinations are approximate, based on our daily analyses from the furnace from which this casting was made: —

Carbon	3.40 –3.60
Manganese	.50 – .55
Phosphorus	.053– .058
Copper	.050– .055
Sulphur	.106
Silicon	1.40."

Dimensions and Treatment of Disk.

The diameter of the disk made from this casting was 10.06 cm.; its mean thickness was called 1.787 cm.; the largest of nine measurements at different places indicating 1.798 cm., and the smallest 1.776 cm.

The copper plating of the disk was effected by giving it first a thin coating from a cyanide of copper solution, such as is used by nickel-platers in preparing iron to receive the nickel, and then finishing the operation by use of a sulphate of copper solution. Much preliminary experimenting in this process was done on a block of the cast iron before the disk was taken in hand, in order to make sure that a good

and strongly adherent coating would be obtained upon the latter at the first trial. The final procedure, which worked well, was as follows: —

Two electrolytic baths were prepared, one consisting of a cyanide of copper solution purchased ready made from a nickel plater, the other being an ordinary sulphate of copper solution of specific gravity about 1.10, acidulated by about one drop of strong sulphuric acid to ten cubic centimeters of the solution. Each solution contained two vertical plates of copper, somewhat broader than the disk to be coated, placed several centimeters apart.

A hole about 0.5 cm. in diameter was bored a short distance into the curved side of the disk, and in this was fixed one end of a steel rod, which was to serve the double purpose of a handle and a conductor of the current from the disk. After being rubbed tolerably bright the disk was boiled in a strong solution of caustic potash for ten minutes, then rinsed in flowing water, then scoured with powdered pumice and water by means of a bristle brush, then dipped some seconds in a 20% solution of hydrochloric acid, then rinsed again in flowing water, then dipped again in the acid solution, then rinsed again, then placed between the two plates of copper in the cyanide of copper solution, which was at a temperature near 70° C., and kept there half an hour with a current of about 3.5 amperes flowing through it. At the end of this time the surface of the disk, including its curved side, was well coated with copper. Accordingly, the disk was taken from the solution, rinsed, covered as to its curved surface with a rubber band to prevent further deposit of copper there, then placed in the sulphate of copper solution between two copper plates about 8 cm. apart; and a current of 3 amperes or more was set to flow through it.

After a number of hours, beads of copper were seen to have formed at the edges of the two flat faces of the disk, and the disk was removed from the solution long enough to allow these beads to be broken or filed off. It was then rinsed, dipped in the hydrochloric acid solution, rinsed again, then replaced in the sulphate bath and again subjected to the current. This course of operations was continued for several days, about 135 hours of current use, until the layer of copper on each face of the disk was about 0.2 cm. thick. At one stage of the procedure it was found necessary to resort to the cyanide bath again for a short time, the filing off of the copper beads at the edges having exposed the iron at certain parts of the convex surface.

The coatings when completed were somewhat thicker near the edge than in the middle. Accordingly, they were turned off in the lathe to a

nearly uniform thickness, though one of them was left slightly thicker at the edge. The final thickness of each coating was not far from 0.2 cm. The convex surface of the disk was turned off sufficiently to leave a good surface and show clearly the junctions of the copper coatings with the iron body. The diameter of the disk was thus reduced to 9.94 cm.

Each coating was now channelled at the edge to a depth of about 0.1 cm. and a width of about 0.17 cm., as in Figure 1 of Plate I., and a brass ring, R or R', 0.3 cm. thick, was shrunk into the channel in each coating. R' is cut through in Figure 1. The object of this detail will appear presently.

Mounting and Use of the Disk.

Figure 2 shows how the disk was placed and used in the experiments on conductivity. In this figure, the scale of which is $\frac{1}{2}$, I represents the disk; c and c' are the copper coatings; and the rings just described can be seen set into the edges of the coatings. The lower ring is shown cut through by horizontal passages. There are, in fact, in this ring 24 horizontal slots, each about 1 cm. long and 0.2 cm. wide, the object of which is to allow the water entering vertically beneath the middle of the disk to flow out horizontally from beneath the disk, thus carrying away the air-bubbles which warm water inevitably contains, and which would accumulate beneath the disk if an immediate downward escape of the water through small passages were required. Upon passing from beneath the disk the water enters a groove cut in a hard rubber ring, $h'h'$, and covered by a brass flanged ring $n\,n$ fastened to $h'h'$. Thence it passes downward and out of the apparatus by several passages of 4 or 5 millimeters in diameter, only two of which are shown in the figure. The slotted brass ring through which the water flows carries the iron disk, and rests in a groove in the hard rubber ring $h'h'$, a soft rubber tube at the bottom of this groove making a water-tight packing. The ring $h'h'$ has at the bottom another groove, which receives the top of the brass ring $r'r'$, which rests upon a wooden support to which it is firmly attached by means of a horizontal flange. Soldered within $r'r'$ near its top is the brass plate $p'p'$, which carries the hard rubber block $H'H'$, in the centre of which is fixed the tube that carries the water to the bottom of the disk. This tube is enclosed for a part of its length by another, which extends downward from $p'p'$; but this is an unimportant detail.

Encircling the iron disk is a soft rubber band $b\,b$, which was intended partly as a protection of the iron against rusting, and partly as a dam to prevent leakage of water upward past $n\,n$. Another similar band, not

shown, rested its lower edge upon $n\,n$; but such precaution against leakage was perhaps hardly necessary. The downward escape of water from the groove in $h'h'$ was so free that there was little tendency for it to overflow $n\,n$.

Starting again at the iron disk and now proceeding upward, we find $h\,h$, $H\,H$, and $p\,p$, corresponding in material and in general shape and position to $h'h'$, $H'H'$, and $p'p'$, already mentioned. The mere weight of the apparatus being insufficient to prevent vertical movement and dislocation under the pressure of the water within, a retaining device was used, which is described as follows. A flat ring of brass, not shown in Figure 2, was provided with three internal radial offsets, each of which bore upon a block of wood resting upon the narrow external flange of $p\,p$. Three brass bolts led from this ring to the brass base-plate of the apparatus, enabling the experimenter to apply to the plate $p\,p$ any necessary amount of downward pressure.

Certain other parts in the upper portion of the figure require explanation. The parts there shown in dotted outline do not lie in the median section of the apparatus, and are to be regarded as behind the plane of the rest of the figure. For example, the vertical tube indicated above J_1 does not rise directly from J_1, but from a horizontal offset extending from J_1 as in Figure 3. Another horizontal offset from J_1 receives, as the same figure shows, one end of a plug, P_1, consisting of two semi-cylindrical pieces of hard rubber pressing between them a strip of soft rubber packing, which packing separates the wires of the copper-German silver junction j_1. J_2, Figure 2, is similar to J_1, and contains a similar junction. More will be said of these junctions later.

Water entering at A flows vertically past the bulb of the thermometer T_1, which gives a rough indication of its temperature, then horizontally past the junction in J_1, then by a brass tube into the funnel-shaped passage FF, then downward through numerous holes near the edge of $p\,p$, and so on, as the arrows show, under HH, upward through the vertical brass tube t_1, which touches the enclosing brass tube t_2 only near the ends of the latter, past the other copper-German silver junction within J_2, past the bulb of T_2, thence out by means of a rubber tube to the lower part of the jacket KK, around and upward through this jacket to the main outlet at O. The jacket has a supplementary outlet at S; and the water from both outlets is collected and weighed below.

Leading upward from the apex of the funnel FF is a small tube, w, through which a slight waste flow of water is maintained in order to carry off air-bubbles from FF. Two openings in the top of the water

jacket give escape for air, and allow the use of thermometers for taking the temperature of the water in the jacket.

This water flows over as well as around the enclosed apparatus. The opening in the double top of the jacket, through which extend the tubes shown above J_1 and J_2 in Figure 2, is about 7.5 cm. by 2.5 cm. Below J_1 and J_2, down to the hard rubber ring $h\,h$, the tubes and funnel were thickly wrapped with cotton to lessen radiation between these parts and the jacket. The space between $h\,h$ and $h'h'$, as well as that around and below $h'h'$, was carefully and fully packed with the same material.

Figure 2 shows two fine copper wires leading out from the coating C, and passing through holes in the hard rubber ring $h\,h$, where they are held in place by means of hard rubber plugs, k_1 and k_2, with soft rubber packing. There are, in fact, see Figure A, p. 290, thirteen such wires, 0.018 cm. in diameter, attached to C by electrolytic deposit of copper by a process sufficiently described in the article referred to in the beginning of this paper. Wire no. 13 is attached at the centre of C; nos. 3, 6, 9, and 12 are attached symmetrically about 2 cm. from the centre; nos. 2, 5, 8, and 11, symmetrically about 3.2 cm. from the centre; nos. 1, 4, 7, 10, symmetrically about 4.4 cm. from the centre. Similar wires, nos. 1′–13′, are similarly attached to the coating C', no. 1′ being immediately beneath no. 1, no. 2′ immediately beneath no. 2, etc. These wires pass through the ring $h'h'$ exactly as nos. 1–13 pass through the ring $h\,h$. To prevent deposit of copper upon the free parts of the wires during the process of attachment, and to prevent illegitimate metallic contacts between the wires and the coatings C and C' during the experiments on conduction, the wires were coated with shellac between the points of attachment to the coatings and the places of exit through the hard rubber rings. Outside the rings each wire was led to a point on a wooden platform, where it was, by means of a screw and copper washers, held in firm copper connection with a larger copper wire. The twenty-six larger wires thus brought into connection led to a like number of small mercury wells in a board placed at some distance from the apparatus shown in Figure 2.

Determination of the Difference of Temperature of the Two Faces of the Disk.

The mercury wells were so arranged that by means of copper connectors reaching from one well to another any point of junction on the upper coating of the iron disk could be thrown into circuit with the corresponding point on the under coating and with an astatic galvanometer.

Care was taken to make the thirteen circuits which could be, one at a time, thus formed very nearly equal in resistance. It was possible to use such copper connectors between the mercury wells as to throw all the wires leading from the upper coating of the disk into multiple arc with each other, and all those leading from the lower coating into multiple arc with each other, and to connect the two sets of wires in one circuit with the galvanometer. The latter mode of connection was finally used in the conductivity experiments; but certain preliminary observations with the single circuits were made in order to find whether the various pairs of junctions on the disk were enough alike in performance to justify connecting them in multiple. The method of testing was to run a stream of water at constant temperature through the apparatus on the under side of the disk, and another stream at a different constant temperature through on the upper side of the disk, and to note the galvanometer deflections obtained from each of the pairs of junctions in turn. The following table shows the result of the observations: —

Deflections.

Junctions.	Oct. 23.	Oct. 26.	Oct. 26.	Nov 8.	Nov. 3.	Mean.	
13 and 13′	4.91	4.38	4.46	4.86	4.74	4.67	
1 and 1′	5.31	4.90	4.87	5.25	5.19	5.10	
4 and 4′	5.08	4.78	4.70	5.20	5.00	4.95	4.83
7 and 7′	4.93	4.55	4.56	4.80	4.60	4.69	
10 and 10′	4.71	4.53	4.40	4.75	4.55	4.59	
2 and 2′	5.06	4.70	4.51	5.15	5.05	4.89	
5 and 5′	5.03	4.70	4.63	5.06	5.00	4.88	4.73
8 and 8′	4.76	4.47	4.40	4.75	4.68	4.61	
11 and 11′	4.66	4.33	4.30	4.76	4.68	4.55	
3 and 3′	4.90	4.67	4.59	5.02	4.98	4.83	
6 and 6′	4.70	4.67	4.59	4.99	4.98	4.79	4.68
9 and 9′	4.66	4.40	4.40	4.76	4.70	4.58	
12 and 12′	4.60	4.33	4.35	4.65	4.70	4.53	

An examination of this table, in connection with Figure A, leads to the conclusion that the mean difference of temperature between the two sides of the disk increases from the centre to the circumference about 3 per cent. It appears, too, that the mean difference of temperature between top and bottom is greater along the radius 1–2–3–13 than along the

radius 4–5–6–13, greater along the latter than along 7–8–9–13, greater along the last than along 10–11–12–13. The mean difference of temperature along 1–13 apparently exceeded that along 10–13 about 6 per

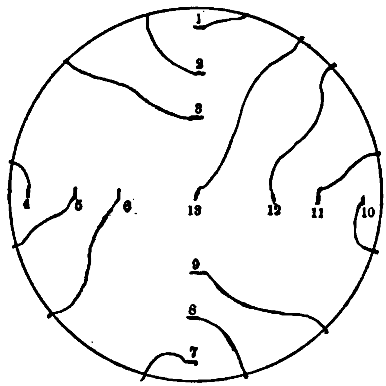

FIGURE A.

cent. A partial explanation of this difference probably is that, on one face or the other of the disk, the flow of water was freer in the region 1–13–4 than in the region 7–13–10. This inequality of flow might be caused by a slight tilting of HH or of $H'H'$ (Fig. 2).

Two short sets of observations were made to compare the deflections given by all the pairs of junctions in multiple with the mean of the deflections given by the pairs used separately. The pair 5–5′ was now found defective, and was omitted from the comparison. The results, after allowance for the smaller resistance of the multiple arc, were as follows : —

	From Multiple Arc.	From Single Pairs.	Ratio.
Nov. 16	4.47	4.37	1.023
" 20	4.37	4.31	1.014

The test of November 20 was the more careful of the two; but even in this test the difference between the ratio found, 1.014, and unity, was within the possible limits of error of observation.

The tests which have been described were considered to justify using the junctions in multiple and treating the current obtained from the combination as representing the mean thermo-electromotive force of the

whole disk, and therefore the mean difference of temperature of the two faces of the iron. There is doubtless some inaccuracy in this conclusion. Strictly, somewhat greater weight should be given to the indications from the outer circle of junctions than to those from junctions nearer the centre; for an inspection of Figure A will show that each of the outer junctions represents a somewhat greater area than one of the inner junctions. The multiple arc method of operation makes no allowance for this fact, but the error from this cause was probably very small. It is to be observed, moreover, that an error of 1%, for example, in the absolute value of the thermal conductivity of a particular piece of iron is of no great consequence in the present state of investigation, provided the change of conductivity with change of temperature can be determined with some degree of accuracy.

Before the experiments upon conductivity were made, a number of the fine wires leading from the faces of the disk having failed, a complete new set of wires, from the same piece as the first set, was put in by the same method and in the same positions as before. The apparatus was then set up once more, in its former condition as nearly as possible.

The strength of the electric current coming from the disk was measured by means of an astatic galvanometer, the sensitiveness, or figure of merit, of which was determined frequently by sending through it a known fraction of a current measured by a good tangent galvanometer. The resistance of the circuit containing the disk and the galvanometer being known, the thermo-electromotive force producing the current from the disk was found. But before this e. m. f. could be translated into difference of temperature between faces of the iron, it was necessary to determine by experiment the e. m. f. arising from some known difference of temperature between two junctions made of copper and of iron like the iron of the disk. For this test a piece about 10 cm. long and 0.16 cm. in diameter was cut from the same slab of cast iron from which the disk had been taken; and to each end of this slender bar a copper wire, from the same piece as the wires attached to the coatings of the disk, was fixed by electrolytic deposit of copper. The bar was set in a hard rubber holder, about 2.5 cm. projecting at each end, and the whole was mounted between two brass tubes in such a way (see Fig. 4) that water flowing through either tube would flow over one end of the bar. Thus water entering at A_1 ran past the bulb of the thermometer T_1 along the end I_1 of the iron, and out at E_1. An alternative exit for the water is indicated by the dotted lines below I_1. A coating of shellac was used to protect the iron and the copper from the chemical action of the water.

In order to eliminate various sources of possible error, including especially disagreement of the two thermometers, sets of observations were made in pairs, the stream entering at A_1 being warmer than the other in the first set of observations and colder than the other in the following set. The difference of temperature was usually between 5° and 10° C.

Some doubt was felt at first as to whether the ends of the bar would have the same difference of temperature as the thermometers. It is evident that use of exits E_1 and E_2, whereby the streams were made to flow a considerable distance along the bar, would be more effective than the use of the dotted exits. The latter were used upon occasion, with the idea that, if they gave about the same effect as E_1 and E_2, the latter could be regarded as satisfactory. The dotted exits gave a result some four or five per cent less than that given by the other exits. It appeared unlikely that any considerable error would be made in assuming that, when E_1 and E_2 were used, the difference of temperature of the ends of the bar was the same as the difference of temperature of the thermometers.

It will be observed, however, that the iron bar used in this test was like a piece cut parallel to a certain *diameter* of the disk, not parallel to the thickness of the disk. It was a matter of very grave doubt whether the thermo-electric quality of the bar, taken lengthwise, could be regarded as identical with the thermo-electric quality of the disk taken thickness-wise. It was the latter quality that came into play in the conductivity experiments; and some way of determining it was to be found. The method which was finally adopted is described in Appendix I. of this paper. It showed that scarcely an appreciable error would have been made by using the results obtained from the first method, above described.

With the information thus obtained it was easy to calculate with considerable accuracy the difference in temperature of the two faces of the iron disk in the conductivity experiments, the indications of the astatic galvanometer being readily interpreted. The deflections of the galvanometer, upon reversal of the current, were usually about 9 cm.; and the difference of temperature of the faces of the iron was usually rather more than 1° C. The difference of temperature of the streams, above and below the disk, was usually about 8° C.

Determination of the Difference of Temperature of the Ingoing and Outcoming Water at the Chamber above the Disk.

The method of making this measurement has already been indicated. Two copper-German silver junctions, each like that shown in Figure 3, were used, one at J_1 in Figure 2, the other at J_2 in the same figure. The German silver wire used, about 0.015 cm. in diameter, was continuous from J_1, Figure 3, to the corresponding junction in the other plug. Its length was perhaps 30 cm. The fine copper wire, 0.018 cm. in diameter (from the same piece as the wires attached to the coatings of the disk), leading from J_1, Figure 3, did not extend completely through the hard rubber plug, or holder, but was soldered carefully, some distance from the outer end of the plug, to a larger copper wire, which led off toward an astatic galvanometer. The arrangement of copper wires at the other plug was quite similar. The fine wires of each junction were coated thinly with shellac.

The two copper-German silver junctions thus described, or similar ones,* were tested, or "calibrated," by means of streams of water, of a known difference of temperature, flowing past the junctions according to the arrows in Figure 3. The difference of temperature of the streams was found by means of the same pair of thermometers that are indicated in

* In accordance with my advice, Mr. Ayres made only such experiments in the calibration of his copper-German silver junctions as to show that their performance differed but little from that of similar junctions used previously by myself. After this, in all his calculations of the conductivity, he took his values of the thermo e. m. f. of copper-German silver from Figure 8 of my previous paper, already referred to, "On the Conductivity of Mild Steel." In preparing the present paper, I have had some misgivings as to the accuracy of these values, and therefore in October, 1898, I made more experiments upon a pair of junctions quite similar to those used by Mr. Ayres. The results are given in the second column below. The third column gives values, for the same temperatures, taken from the figure used by Mr. Ayres: —

Mean Temp.	Electromotive Force, in Volts, per 1° C. Difference of Temperature of Junctions.	
20°.3	.00001743	.00001732
37°.9	.00001826	.00001830
58°.2	.00001944	.00001942

From the old observations and the new combined a curve representing the thermo e. m. f. at temperatures ranging from 15° to 65° was constructed, and the values of the conductivity found by Mr. Ayres were revised accordingly. The resulting changes of conductivity were slight, but they had considerable effect upon the estimated temperature coefficient of conductivity. — E. H. H.

Figure 4, and the same method of alternating the hotter and cooler streams was used here that was used in the test of the copper-iron junctions. The difference of temperature of the streams in the calibration tests was usually about 4° or 5° C.

In the conductivity experiments proper, the usual difference of temperature of the copper-German silver junctions, the usual difference of temperature, that is, of the ingoing and outgoing water, was probably rather more than 0°.5 C.

The Flow of Water.

The method of controlling and heating the streams of water was essentially the same as that described in the previous paper,* and illustrated in Figure 5 of that paper. Powerful gas-burners, of a type manufactured by the Buffalo Dental Company and expressly intended for heating streams of water, were used. Each stream flowed through the conduction apparatus from the base of an overflowing standpipe, which device answered the double purpose of insuring a constant flow, and allowing air bubbles to escape from the water before reaching points where they would do harm. A supplementary air-vent was provided for the upper stream near its entrance at *A*, Figure 2.

The stream which flowed above the disk, the only one upon which careful measurements were made, ran into a covered barrel standing upon a platform balance. The time of flow was noted, and the amount of water accumulating in the barrel during that time was determined by weighing. The rate of delivery of the stream ranged, during the whole course of the investigation, from about 15 grams per second to about 25 grams per second. The stream flowing beneath the disk was of the same order of magnitude.

Results and Discussion.

A few sets of observations were made at low temperatures without the use of the jacket. A few others were made at various temperatures with use of jacket, but without the cotton packing within and below it. These observations were preliminary, and none of them will be used in deducing the final results. The detailed results of subsequent observations, made with jacket and cotton packing in use, are given below in chronological order. None are omitted, although some are placed in brackets for reasons to be given later.

* These Proceedings, Vol. XXXI., 1896.

The "mean temperature" is the mean between the temperature of the upper stream upon entering the apparatus (as indicated by the thermometer T_1 in Fig. 2), and the lower stream upon leaving * the apparatus. Neither of these temperatures was taken with great accuracy, and any one of the mean temperatures given may be wrong to the extent of 0°.5.

Date, 1897.	Mean Temp.	K_1	K_2	K
May 11	21°	0.1471	0.1495	0.1483
" 13	19°.6	0.1489	0.1558	0.1524
" 15	20°.4	0.1503	0.1511	0.1507
" 18	39°.1	0.1485	0.1489	0.1487
" 20	40°.9	0.1512	0.1520	0.1516
" 25	22°	0.1522	0.1515	0.1519
" 26	40°.2	0.1482	0.1494	0.1488
" 28	20°.6	0.1533	0.1507	0.1520
" 29	35°.7	0.1523	0.1494	0.1509
June 7	74°	0.1421	0.1309	0.1365
" 8	72°.9	0.1523	0.1559	0.1541
" 21	77°.3	0.1382	0.1400	0.1391
" 23	21°.7	0.1536	0.1465	0.1501
" 26	56°.2	0.1506	0.1407	0.1457
[July 1	55°.5	0.1741	0.1443	0.1592]
[" 2	61°.6	0.1584	0.1188	0.1386]
[" 8	58°.5	0.1564	0.1425	0.1495]
" 23	54°.2	0.1518	0.1487	0.1503
" 24	57°.3	0.1485	0.1423	0.1454
" 26	28°.4	0.1496	0.1504	0.1500
[" 30	74°.6	0.1368	0.1588	0.1478]
Aug. 3	56°.5	0.1427	0.1441	0.1434
" 4	27°.5	0.1557	0.1528	0.1543
" 7	27°.0	0.1519	0.1515	0.1517
" 8	59°.2	0.1470	0.1446	0.1458

Under K_1 are given values of the conductivity obtained from observations made when the warmer stream ran above the disk. Under K_2 are given values of the conductivity obtained from observations made when the warmer stream ran below the disk. K is the mean of K_1 and K_2. In the calculation of the values here given, no account was taken of the

* The temperature of the lower stream on *entering* the apparatus was not taken; but the change of temperature within the apparatus was slight.

variation of the specific heat of water with variation of temperature, this specific heat being called 1 for every temperature used. This inaccuracy will be referred to again.

These figures show a considerable range of temperature, and from them it should be possible to derive an approximate value at least of the temperature coefficient of K. The numbers given in brackets, however, will not be used for this purpose. The numbers for July 1, 2, and 8 exhibit great differences between K_1 and K_2, and also between the values of K. On those days, and those only, the pair of copper-German silver junctions, used to determine the change of temperature of the upper stream, were covered with shellac *melted* on. The coating thus obtained was too thick, so that the junctions did not take the temperature of the water with sufficient readiness. There are in the table above given other values of K obtained at temperatures not very different from those at which these rejected values were found. The values obtained for K at all temperatures above 70° differ much among themselves; but it hardly seems best to reject them altogether in the attempt to arrive at an approximate value of the temperature coefficient of K. The great variation observed among them was probably due to unsteadiness of temperature of the water streams when very hot, or to possible impairment by the hot water of the shellac coating on the copper-German silver junctions.

All the values of K not contained within the bracketed lines will be used in some fashion in estimating the temperature coefficient; but they will be used in two divisions, one for May and June, the other for July and August. The reason for this division is that on August 5 some of the lines of wire leading from the copper coatings on the iron disk were found to be out of condition. The pairs of wires affected were 1, 2, 11, and 12, the other nine pairs remaining in good condition. When this partial breakdown began it is impossible to determine; June 30 was the last date on which all the pairs of wires were known to be in good order. It has been shown in the early part of this paper that each pair of wires gave about the same effect as any other pair; therefore, as all were joined in multiple, the failure of a few of them should affect the total current but little, the resistance of the remaining pairs being but a small part of the total resistance of the circuit. The failing pairs lay, one in the outermost circle, two in the next, and one in the next. It appears, from a comparison of the values of K obtained near 21° and near 39° in May and June with the values obtained near 28° in July and August, that the impairment of the wires or some other unknown

cause made the later values at a given temperature about one per cent greater than they would have been had they been obtained at the same temperature in May or June. In these earlier months sets of observations were made at various temperatures from near 20° to near 75°. In July and August sets near 28° were intermingled with sets near 57°. It is possible, therefore, to make for each period an independent determination of the temperature coefficient of K.

We have from the May and June division: —

Date.	Mean Temp.	K_1	K_2	K
May 11	21°	0.1471	0.1495	0.1483
" 13	19°.6	0.1489	0.1558	0.1524
" 15	20°.4	0.1503	0.1511	0.1507
" 25	22°	0.1522	0.1515	0.1519
" 28	20°.6	0.1533	0.1507	0.1520
June 23	21°.7	0.1536	0.1465	0.1501
	20°.9	0.1509	0.1509	0.1509
May 18	39°.1	0.1485	0.1489	0.1487
" 20	40°.9	0.1512	0.1520	0.1516
" 26	40°.2	0.1482	0.1494	0.1488
" 29	35°.7	0.1523	0.1494	0.1509
	38°.9	0.1501	0.1499	0.1500
June 26	56°.2	0.1506	0.1407	0.1457
June 7	74°	0.1421	0.1309	0.1365
" 8	72°.9	0.1523	0.1559	0.1541
" 21	77°.3	0.1382	0.1400	0.1391
	74°.7	0.1442	0.1423	0.1432

From July and August we have: —

Date.	Mean Temp.	K_1	K_2	Mean K
July 26	28°.4	0.1496	0.1504	0.1500
Aug. 4	27°.5	0.1557	0.1528	0.1543
" 7	27°.0	0.1519	0.1515	0.1517
	27°.6	0.1524	0.1516	0.1520
July 23	54°.2	0.1518	0.1487	0.1503
" 24	57°.3	0.1485	0.1423	0.1454
Aug. 3	56°.5	0.1427	0.1441	0.1434
" 8	59°.2	0.1470	0.1446	0.1458
	56°.8	0.1475	0.1449	0.1462

The single set of observations, made July 30, at a temperature near 75° is hardly worth taking into account here, the uncertainty of observations at such a temperature being great, as we have seen.

According to the evidence thus far we have, from the May and June observations,

at 20°.9	$K = 0.1509$
" 38°.9	" $= 0.1500$
" 56°.2	" $= 0.1457$ (?)
" 74°.7	" 0.1432 (?)

and from the July and August observations,

at 27°.5	$K = 0.1520$
" 56°.8	" $= 0.1462$

As the change of K with change of temperature appears to be small in any case, it becomes important to consider the change of specific heat of water with change of temperature; for all values which precede are given on the assumption that the specific heat of water is 1 at all temperatures used.

Winkelmann, in Part II. of Volume II., p. 340, gives a table of the specific heats of water, which he has deduced from a formula proposed by himself after a discussion of the results obtained by numerous experimenters. This table gives: —

Temp.	Sp. Heat.	Temp.	Sp. Heat.
0° C.	1.0000	50° C.	0.9939
10°	0.9944	60°	0.9992
15°	0.9924	70°	1.0067
20°	0.9910	80°	1.0164
25°	0.9901	90°	1.0283
30°	0.9898	100°	1.0424
40°	0.9907		

Revising, in accordance with this table, the values of K last given above, we get,

at 20°.9	$K = 0.1494$
" 38°.9	" $= 0.1485$
" 56°.2	" $= 0.1453$ (?)
" 74°.7	" $= 0.1447$ (?)
" 27°.6	" $= 0.1505$
" 56°.8	" $= 0.1458$

The difference between the value of K found for 20°.9 and that found for 38°.9 is so slight that very little importance can be attached to it, in view of the much greater differences between successive measurements of K at or near any one temperature. Making the formal calculation, however, from these values as they stand, we get, as the temperature coefficient of K between 20°.9 and 38°.9,

$$\frac{0.1494 - 0.1485}{0.1494\,(38.9 - 20.9)} = -0.00033.$$

Taking the mean of 20°.9 and 38°.9 and the mean of 0.1494 and 0.1485, we have, at 29°.9, $K = 0.1490$. Taking this as a starting point, we find, for the temperature coefficient of K between 29°.9 and 56°.2,

$$\frac{0.1490 - 0.1453}{0.1490\,(56.2 - 29.9)} = -0.00094.$$

Similarly, we find between 29°.9 and 74°.7,

$$\frac{0.1490 - 0.1447}{0.1490\,(74.7 - 29.9)} = -0.00064.$$

So much for the May and June numbers.

From the July and August numbers we get, between 27°.6 and 56°.8,

$$\frac{0.1505 - 0.1458}{0.1505\,(56.8 - 27.6)} = -0.000107.$$

The mean of all these estimates of the temperature coefficient of K is —0.00075, according to which the thermal conductivity of the cast iron disk diminishes about 1% for each 13°.3 rise of temperature within the limits of the observations above recorded. According to experiments described in Appendix II. following this paper, the temperature coefficient of electrical conductivity of the same cast iron, between 17° and 67°, is —0.00118; which means that the electrical conductivity between these limits diminishes at the rate of 1% for each 8.°5 rise of temperature. At one time during the preparation of this paper it appeared that the two temperature coefficients were very nearly equal. This led to a more careful examination of the evidence than had been made before, and a repetition of certain measurements, with the result given above. It may yet be that the two coefficients are equal. Where both are so small the question of equality or inequality is difficult to settle, although

a new series of experiments with same cast iron disk would probably give results much more concordant than those set down in this paper. In wrought iron the temperature coefficient of electrical conductivity is much greater than in cast iron, and if the temperature coefficient of thermal conductivity is correspondingly large in wrought iron, fairly accurate measurements of this latter coefficient should be attainable with this material. A disk of wrought iron will probably be put to the test before long. The disk of mild steel used in the experiments described in a preceding paper was very like wrought iron in many respects; but it has already been stated, in the first part of this paper, that the experiments with this disk were not entirely satisfactory, the disk itself and its copper coverings being too thin for the best effect.

The experiments of this paper have given a larger value of K, for the piece of cast iron dealt with, than was expected. It is much larger than the value, about 0.105, found some years ago for two specimens of cast iron near 115°C. by one of the authors * of this paper, using the method of Forbes. It is much larger than the values found by Kohlrausch and by Wiedemann and Franz for soft steel near 15°. Nevertheless, there seems to be no good reason for doubting the substantial accuracy of the value of K found in this paper. The most novel, and perhaps the most doubtful, feature of the method here described is the use of the iron itself as part of a thermo-electric element. How carefully the thermo-electric behavior of the iron with respect to copper has been considered will be apparent to the reader of Appendix I.

Another subject of possible doubt is the amount of error caused by neglect of radiation or convection between the water jacket, Figure 2, and the apparatus surrounded by it. The value found for K is affected, 1st, by such interaction as occurs between the jacket and the disk; 2d, by that between the jacket and those surfaces which lie above the disk and below J_1 and J_2. The mean temperature of the curved surface of the disk was probably four or five degrees below the temperature of the jacket when the warm stream ran above, and nearly an equal amount above that of the disk when the cold stream ran above. The area of this surface between the two hard rubber rings $h\,h$ and $h'h'$ was about 50 sq. cm. Preston, "Theory of Heat," p. 461, gives, as found by McFarlane for a blackened sphere suspended within a water jacket 5° cooler than itself, "*heat emitted per second, per degree difference of temperature,*

* E. H. Hall, in these Proceedings, 1892, p. 262.

per square centimeter in water-gram units" equals 0.000252. Assuming this rate of emission or absorption for each of the 50 sq. cm. of the curved surface of the disk, we should get for the passage of heat per second $50 \times 0.000252 \times 5 = 0.063$ units. The heat passing per second through the disk from face to face was usually about one hundred times as much as this. If we assume, for the moment, that the passage of heat through the curved surface of the disk is equal to 1% of that which flows from face to face, we may thereupon reason as follows. When the warmer stream flows above the disk, the disk takes in heat from the jacket, and the total amount passing out through the lower face of the disk exceeds by 1% the amount flowing in at the upper face. The inflow at the curved surface distorts the isothermals and lines of flow within the disk in such a way that, with a given difference of temperature between the faces, the flow from face to face, which is equal to the inflow at the upper face, is less than it would be if the flow within the disk were *adiabatic*, that is, if there were no inflow at the curved surface. On the other hand, the outflow at the lower face is greater than the adiabatic flow from face to face would be. We may conclude that, under the conditions assumed, the actual inflow at the upper face is about 0.5% less than the adiabatic flow would be with like temperatures at the faces, and that the outflow at the lower face is about 0.5% greater than the adiabatic flow would be. Our method of calculating K assumes adiabatic flow, while our observations give us the inflow at the upper surface. Accordingly, under the conditions here assumed, the value obtained for K would be about 0.5% too small. A similar error, *in the same direction*, would be made with the colder stream flowing above the disk, so that we could not eliminate it by combining two sets of observations. In fact, however, the assumption that the rate of transmission at each square centimeter of the curved surface of the disk, thickly wrapped with cotton, is the same as that found by McFarlane for a bare blackened surface of copper, gives a very large overestimate of the possible error from this source.

Turning now to the surfaces between the top of the disk and the parts J_1, J_2, Figure 2, we find the area of these surfaces to be about 300 sq. cm. No systematic observations of the temperature of the jacket were kept during the experiments of which this paper gives an account, but from previous observations it appears probable that the mean temperature of the jacket was about 1° C. lower than the temperature of the parts which we are now considering, when the warmer stream ran above, and 0°.5 or less higher than the temperature of these parts when the colder stream ran above. Assuming the difference of temperature

to have been 1° C., and assuming, for the moment, the same rate of surface transmission which we have used above, we get, as the amount of heat passing per second between the parts considered and the jacket, $300 \times 0.000252 = 0.0756$ units. This is, perhaps, rather more than 1% of the heat carried from face to face through the disk, and if it were a fair estimate of the actual transmission between the jacket and the surfaces considered, the neglect of this transmission would make K, as calculated, about 1% too large. This error would not be eliminated by combining sets of observations, some with the warmer stream above, and some with the colder stream above. But in this estimate, as in that relating to the action at the curved surface of the disk, the rate of transmission assumed is no doubt much too large, the surfaces enclosed by the jacket being, for the most part, well wrapped with cotton.

It seems, therefore, unlikely that any considerable error was made by neglecting the interchange of heat between the water jacket and the apparatus within it.

There is little doubt that much more concordant values of K than those given in this paper can be obtained by a somewhat more careful control of the temperature of the water, and by making each set of observations longer than the sets, often very brief, which were made in the investigation which has here been described.

Summary.

The thermal conductivity of the cast iron used is about 0.1490 at 30° C. The temperature coefficient of thermal conductivity, if Winkelmann's rule for the change of specific heat of water with temperature is correct, appears to be about −0.00075 between 20° and 75°, so that a rise of about 13° C. corresponds to a fall of 1% in conductivity.

If the change of specific heat of water between 30° and the higher temperatures up to 75° were neglected, the value found for the temperature coefficient would be about −0.0010.

The electric conductivity of this cast iron is about 112,200 in c. g. s. units. (See Appendix II.)

The temperature coefficient of its electric conductivity between 17° and 67° is about −0.00118.

The method used appears to be capable of giving better results than have yet been obtained by it.

APPENDIX I.

Measurement of the Thermo-Electric Quality of Short Iron Bars.

When it became necessary to determine, relatively to copper, the thermo-electric quality of the cast iron disk thickness-wise, the problem appeared to be one of some difficulty. The thickness of the disk was about 1.8 cm. The thickness of the slab from which the disk had been taken was such that bars 2 cm. long could be cut from it thickness-wise; but to make satisfactory thermo-electric measurements upon a single bar of this length appeared to be impracticable. The device of putting a number of such bars end to end, so as to make a column of considerable length, and placing this column lengthwise between two blocks of copper of different temperatures, seemed a hopeful one; but it had to be put to the proof before it could be used with confidence.

Accordingly a very soft magnet core rod, about 0.16 cm. in diameter, was taken, and from it were cut one piece 15 cm. long and ten pieces each 2 cm. long. Copper wires were soldered to the ends of the 15 cm. piece, and this piece was then mounted very much as the piece I_1I_2 is mounted in Figure 4. The parts exposed to the streams were now, however, some 5 cm. long, about twice as long as the exposed parts in similar preceding tests. A thin coating of paraffine was now used to protect these parts from the chemical action of the water.

The ten 2 cm. pieces, after being carefully cleaned and polished at the end surfaces, were placed end to end in a wooden tube, which in all its dimensions was much like the wood of a common pencil from which the graphite has been taken out. The iron, corresponding in position to the graphite of a pencil, projected from the wood about 0.2 cm. at each end. *R R* in Figure 5 (Plate II) shows in diagonal lines a section of the wooden tube, or rod, the iron within being indicated by a heavy black line; the scale of the figure is ½. Water jackets, J_1 and J_2 in Figure 5, surrounded *R R* for the greater part of its length. The iron column projecting from *R R* was pressed between two copper blocks $B_1\,B_1$ and $B_2\,B_2$, through which flowed streams of water at any temperature required. The pressure was applied by means of a wooden plunger *p*, supported in the block *b*, and pushed against $B_2\,B_2$ by a fairly constant force. The blocks $B_1\,B_1$ and $B_2\,B_2$ were of the same diameter as the jackets j_1 and j_2, and all of these objects rested in a slot cut lengthwise in a piece

of hard wood. S, S, S, in the figure, are parts of this wooden support which would have been cut through by a vertical longitudinal section through the middle of the apparatus. Certain edges of the support which do not form part of the section shown are indicated in the figure by light dotted lines. Behind, to the left of, the block B_1 B_1, is shown a copper wire W_1, about 0.1 cm. in diameter, which extends through the centre of a wooden rod r and bears against B_1 B_1, thus making a back-stop for the pressure exerted at the other end of the apparatus. From the block B_2 B_2 another copper wire, W_2, held in firm contact with B_2 B_2, leads away. The wires W_1 and W_2 are parts of the thermo-electric circuit of the apparatus, and are in metallic connection with the terminals of a galvanometer. B_1 B_1 is provided with a water jacket J_1 J_1, the construction of which is indicated by certain lines in Figure 5 and in Figures 6, 7, and 8. Thus, Figure 6 shows a vertical cross-section through J_1 J_1 near the left end of B_1 B_1, the dotted lines indicating certain edges not lying in this section. Figure 7 shows a vertical cross-section through J_1 J_1, through B_1 B_1, and through the thermometer T_1 (Fig. 5). Figure 8 shows a horizontal section through J_1 J_1 and B_1 B_1. The block B_2 B_2 is protected by a jacket quite similar to J_1 J_1. Wads of cotton were used to protect certain parts of each block which were not covered by the jackets.

The course of the water through the apparatus is indicated by arrows. Thus, at the left hand the streams enters at A, passes down along the bulb of T_1 through B_1 B_1, thence by a rubber tube, longer in fact than in the figure, to J_1 J_1, thence by another rubber tube to j_1, and out at E_1. The flow of the right hand stream is strictly analogous. Each stream usually carried 20 or more grams of water per second. The thermometers T_1 and T_2 were the same that were used with the 15 cm. bar of iron and in previous tests of thermo-electric junctions. Sets of observations at a given mean temperature were made in pairs, one set having T_1 the warmer, the other set having T_2 the warmer.

It was necessary to give careful attention to the electrical resistance of the column of short iron bars; for it could not be safely assumed that this resistance would be either small or constant. It was found, naturally, to depend somewhat upon the magnitude of the pressure applied at the ends of the column. In the experiments upon soft iron which we are just now considering, the pressure was exerted by means of a compressed piece of india-rubber tubing, not shown in Figure 5. In later experiments, with cast iron, it was applied through a lever as in Figure 5, the force F being exerted upon the end of the lever by means of a

spring balance at a point too far down to be shown in place. With the rubber tube in use the pressure against the end of the column was perhaps 1.8 kilograms. When the lever and balance were used, it was sometimes about three kilograms and sometimes less.

The various jacketing and protecting devices shown in Figure 5 were not all used at first, and in the early experiments on soft iron the e. m. f. obtained from the column of short bars was several per cent less than that obtained from the 15 cm. soldered bar, with a given difference of temperature between the two thermometers. This discrepancy gradually diminished as the method of experimentation was improved, until at last it became little or nothing, as the following numbers, obtained with the system of jacketing shown in Figure 5, will testify.

	With Soldered Bar.		With Column of Short Bars.	
Date, 1898.	Mean Temp.	E. M. F. Per Degree Diff. of Temp.	Mean Temp.	E. M. F. Per Degree Diff. of Temp.
April 9	14°.5 C.	[214.7]	14°.5	[209.6]
" "	18°.4	214.2	18°.4	212.6
" 20	20°.9	213.2	20°.9	211.0
" "	16°.9	215.8	17°.0	214.3
" 22	18°.4	214.2	18°.4	214.4

The e. m. f. is here given in terms of a purely arbitrary unit. The values in brackets were obtained under conditions of special uncertainty as to resistance. Considering the final trials of the end-to-end short bar method satisfactory, I proceeded to apply it to cast iron. From the end of the slab that furnished the conductivity disk a slice was cut crosswise, about 10 cm. long, 2.5 cm. wide, and 0.3 cm. thick. This was cut up into 26 parts, and each of these parts was turned down to a thickness of about 0.16 cm.; or, rather, 18 of them were so treated, the other 8 being broken at some stage of the operation. They were then boiled for about 20 minutes in a strong solution of caustic potash, partly to free them from oil, partly because the disk had been thus heated before its conductivity was tested. In all of this work an attempt was made, and I think a successful one, to keep the bars in the same order with respect to each other that they had before being cut from the slice, so that I could at the end tell what bars had been taken from near the end of the slice and what ones from near the middle.

When ready for the test of thermo-electric quality, I rubbed the flat ends of each little bar bright with infusorial earth, and wiped them carefully; for it is evident that a particle of dirt or of vegetable fibre left

upon one of the ends may break altogether the electric circuit of which the column of bars should form a part. In later work it seemed better to rub the ends with fine emery paper, and then wipe them upon smooth hard-finished paper to remove adhering particles of dust.

Bars 1, 3, 5, 7, 9, 11, 14, 17, 19, and 23, the numbers indicating their order from one end toward the other of the slice from which they had been cut, were placed in the order just given, end to end in the apparatus shown by Figure 5. The resistance of the column, which in the case of soft iron bars had been about 2 ohms under a pressure of 1.8 kgm., was now found to be surprisingly large. It diminished with increase of pressure, but even with a pressure of 3 kgm. was at first, June 30, about 16.5 ohms. Under a nearly continuous application of this pressure it gradually grew less, until, on July 2, it was about 5 ohms, after which it changed but little, although it appeared to be somewhat greater on July 4.

With this set of bars, and with the method already described, the following results were obtained: —

Date.	Diff of Temp. between Ends.	Mean Temp.		E. m. f. in Volts per Degree.	
June 30, 1898,	9°.84	29°.3	29°.7	.00000549	.00000549
July 4, "	10°.21	30°.1		.00000549	
" " "	11°.97	45°.2			.00000593
" 2, "	13°.40	63°.2	63°.1	.00000649	.00000646
" 4, "	15°.13	63°.0		.00000643	

On November 4, 1898, observations were made in the same way with ten cast iron bars taken from the same set as those used in June and July; whether the same bars or not, could not be told. The result was:

Date.	Diff. of Temp.	Mean Temp.	E. m. f. per Degree.
Nov. 4	10°.24	29°.7	.00000550

It should be remembered that the end to end method of experimentation with short bars of cast iron was adopted because of a doubt as to the availability of the thermo-electric test made by a different method on a 10 cm. bar cut crosswise from the cast iron slab. This earlier method had given: —

Mean Temp.	E. m. f. per Degree.
14°	.00000507
18°.6	.00000518
40°.6	.00000576
63°.3	.00000647

A comparison of these results with those obtained by the end to end method with short bars, cut thickness-wise from the slab, shows that the two methods gave almost identical results. Of course, it is possible that the bars used in the two methods differed considerably in thermo-electric quality, and that some error in one or the other method compensated for and obscured this difference of quality; but it is much more reasonable to conclude that the slab from which all of the bars were cut had practically the same thermo-electric quality crosswise as thickness-wise, and that the accuracy of each method of testing this quality is affirmed by its concordance in results with the other method. The results of both methods were used for plotting a line from which values of the copper-iron thermo e. m. f. could be derived for purposes of interpolation. This line is a curve ascending with increase of temperature, and slightly concave upward. The divergence of this line from true rectitude is probably not very significant. There is in the corresponding curve for the thermo e. m. f. of the copper-German silver junctions, described in the preceding pages, a divergence of about the same relative amount in the same direction. It is possible that this peculiarity of both lines is due to some idiosyncrasy of the thermometers used in the thermo-electric tests. The same thermometers were used in all these tests; and therefore, as the method of calculation of conductivity involved the ratio of the e. m. f. of copper-iron and copper-German silver, no final error as to conductivity results from any small imperfections of these thermometers.

E. H. H.

APPENDIX II.

Measurement of Electric Conductivity of the Cast Iron.

One of the 2 cm. bars described in Appendix I. was used for this determination. Four copper wires were attached to this bar by electrolytic deposit of copper. Two of the wires were about 0.08 cm. in diameter; these were attached to the flat ends of the bar, and served to carry in and out an electric current of about 0.25 ampere. The other two wires were much finer, about 0.018 cm. in diameter; these were attached at two points about 1.7 cm. apart, each being about 0.15 cm. from one end of the bar, and were used for making connection with a potentiometer. The bar was submerged in oil during the measurements. The temperature of the oil was controlled by water flowing through

a lead tube bent into solenoidal form. The bar was placed horizontal within the solenoid, the axis of which was vertical.

The electrical resistance in absolute c. g. s. measure was about 112,200 at 17°.4.

From the observation of September 20, 1898, the temperature-coefficient of conductivity between 20°.9 and 61°.2 appeared to be —0.00120. The observations of September 27, between 17°.4 and 67°.4, gave —0.00116. We may take the mean, —0.00118. In both cases the coefficient was calculated by the formula

$$\textit{Coefficient} = \frac{\text{Cond. at high temp.} - \text{cond. at low temp.}}{\text{Cond. at low temp.} \times (\text{high temp.} - \text{low temp.})},$$

without reference to 0°.

E. H. H.

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ON THE OPTICAL CHARACTERS OF THE VERTICAL ZONE OF AMPHIBOLES AND PYROXENES; AND ON A NEW METHOD OF DETERMINING THE EXTINCTION ANGLES OF THESE MINERALS BY MEANS OF CLEAVAGE PIECES.

BY R. A. DALY.

WITH THREE PLATES.

ON THE OPTICAL CHARACTERS OF THE VERTICAL ZONE OF AMPHIBOLES AND PYROXENES: AND ON A NEW METHOD OF DETERMINING THE EXTINCTION ANGLES OF THESE MINERALS BY MEANS OF CLEAVAGE PIECES.

By R. A. Daly.

Presented by John E. Wolff, December 14, 1898. Received December 15, 1898.

It is evident that, in an optical examination of monoclinic minerals with coincident optical and crystallographic planes of symmetry, the angle of extinction on (010) is a highly important datum, for it is indispensable to a knowledge of the shape and orientation of the ellipsoid of elasticity. The difficulty of preparing sections in the plane of symmetry of amphiboles and pyroxenes, and the practical impossibility of doing so in the case of very small crystals, lead the student of these species to revert to those good natural sections, cleavage plates, and inquire as to the relation subsisting between the extinction on sections parallel to (010) and that on prismatic cleavage flakes. This relation is not simple, and it was long ago demonstrated that, accepting Fresnel's optical theorem, the extinction on (110) is dependent in a complex way on the angle of extinction on (010) and on the optical angle. Michel Lévy made it clear that, for pyroxenes, the extinction on (110) would always be less than on (010), since the latter is the maximum possible value of extinction read against cleavage cracks on any section in the vertical zone. On the other hand, it was shown for the negative amphiboles that among the infinite number of possible sections made by a plane revolving in the vertical zone from (010) to (100), there is one which has the highest value of extinction in that zone, and that this value decreases as the revolving plane moves toward (010) or (100).* It is interesting to determine whether an amphibole with this property of showing a maximum of extinction for positions of the rotating plane between (010) and (100) could have an extinction-angle on (110) greater than that on

* Fouqué and Michel Lévy, Minéralogie Micrographique, p. 368.

(010). It seems to have been taken for granted by some writers that this is not true.*

It is the object of this paper to make a systematic statement of the relation between the extinction on (110) and on (010), and to indicate under what conditions the former may be used to determine the latter. First, there will be deduced a formula to express the extinction on any plane of the vertical zone when the optical angle $2V$ and ρ, the angle of extinction on (010), are known, and a graphic representation of possible extinctions in that zone will be attempted. Then specific tables will be introduced to show how $2V$, ρ, and θ' are related for any variety of pyroxene or negative amphibole, where θ' represents the extinction on a cleavage plate of that variety. Secondly, a method is proposed for the determination of ρ by means of θ' and a new angle of extinction, θ'', found after turning the cleavage piece through a certain angle about the vertical axis.

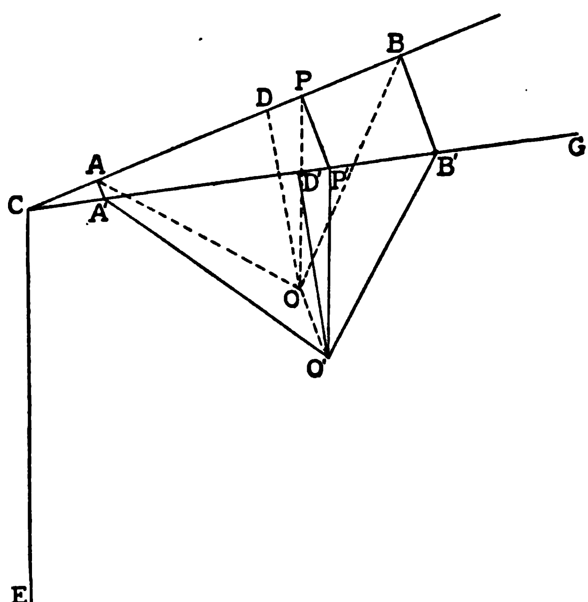

FIGURE 1.

In Figure 1, let $E\,C\,B\,O$ be the plane of symmetry of any monoclinic crystal characterized by parallelism between (010) and the optical plane. Let $E\,C\,G$ be any plane in the vertical zone cutting the plane of sym-

* Rosenbusch, Physiographie der petrographisch wichtigen Mineralien, 3te Auflage, 1892, p. 550. Zirkel, Lehrbuch der Petrographie, 2te Aufl., Bd. I. p. 302.

metry in CE, and BCG a plane cutting the vertical zone at right angles. Let OP represent the vertical crystallographic axis, OD the direction of extinction on (010), AO and BO the optic axes. Let $O'P'$ be the rectangular projection of OP on ECG, O' representing the similar projection of O on ECG. Further, let $O'D'$ be the direction of extinction on ECG, and $A'O'$ and $B'O'$ respectively the lines of intersection of the planes AOO' and BOO' with the plane ECG. Let the angle $BCB' = C$, $\angle POA = \alpha$, $\angle POB = \beta$, $\angle P'O'A' = \alpha'$, $\angle P'O'B' = \beta'$. We have also $\angle P'O'D' = \theta$ and $\angle POD = \rho$.

This construction represents an application of Fresnel's fundamental law that, for a biaxial mineral, the direction of extinction in any section is found by taking the intersection of the plane of the section with that which bisects the angle between the two planes respectively containing an optic axis and the line (ray of light), perpendicular to the section.

It follows that

$$\rho = \alpha - \frac{\alpha + \beta}{2} = \frac{\alpha - \beta}{2},$$

$$\text{and} \quad \theta = \frac{\alpha' - \beta'}{2}.$$

$$\tan \alpha = \frac{\tan \alpha'}{\cos C};$$

$$\tan \beta = \frac{\tan \beta'}{\cos C};$$

$$(1) \qquad \tan 2\rho = \frac{\tan \alpha - \tan \beta}{1 + \tan \alpha \tan \beta};$$

$$(2) \qquad \tan 2\theta = \frac{(\tan \alpha' - \tan \beta') \cos C}{1 + \tan \alpha' \tan \beta' \cos^2 C}.$$

Equation (2) is a special case of Michel Lévy's general formula on page 65 of the "Minéralogie Micrographique," and also of the new formula by Cesàro for expressing the extinction on any face of a zone.* The mathematical treatment of these expressions shows that, as the section moves continuously from the position (010) to the position (100), it will pass through an intermediate position of maximum extinction, if the angle $2V$ be less than 90°, or the angle $(\alpha + \beta)$ greater than 90°. Thus, θ has a maximum when $\cos c = \dfrac{1}{\sqrt{\tan \alpha \tan \beta}}$.† This is true of

* Mémoires de l'Académie Royale des Sciences, etc. de Belgique, 1895, Vol. LIV. p. 26. Ref. in Zeit. für Kryst., etc., 1897, p. 181.

† The position of the section where an extinction may be observed between

all amphiboles so far as known, except pargasite and a very few other varieties; with these exceptions, each has a maximum in a section far removed from the plane of symmetry. A striking example is to be found in an interesting amphibole rich in ferrous oxide from Philipstad, Sweden. It has a pronounced zonal structure; all the zones extinguish together in (010) at 15° 9′, but at different angles on (110), the latter varying from 21° to 17°, corresponding to different and unusually small optic angles in the respective zones of from 50° to 60°.

Plates I., II., and III. represent diagrammatically the variation which may be observed in the behavior of certain negative amphiboles that have such maxima of extinction, — namely, those with optical angles of 50°, 60°, 70°, and 80°, and each characterized by extinctions on (010) of 10° (Plate I.), 15° (Plate II.), and 20° (Plate III.). The abscissa represents the angle of rotation of the section out of the plane of symmetry, the ordinate indicates the corresponding angle of extinction. Arrowheads show which plane of the vertical zone possesses the maximum extinction peculiar to each curve, and also the value of that maximum. The diagrams clearly show that the maximum extinction observable in a rock-slide examined for one of these amphiboles would be far from representing the extinction-angle on (010), and data regarding extinctions and pleochroism derived from the study of thin sections would be worthless, if not controlled by this principle. For the sake of comparison, the analogous curves for amphiboles with $2\,V = 90°$ and ρ respectively equal to 10°, 15°, and 20°, appear in the plates. It will be seen that there is no position of maximum extinction between (010) and (100).*

Now, among the possible positions of the movable plane, there is one which surpasses all others in interest except that of the plane of sym-

(010) and (100) just equal to that on (010) may be found from the following unpublished formula by Dr. A. C. Lane of Houghton, Mich.: —

$$\sin x = \frac{1 - \cos^2 \rho - \cos^2 V}{\cos^2 V - \cos^2 \rho},$$

where x is the angle made with (100) by the required section.

* It is characteristic of all the curves, that the angle of extinction changes very slowly in passing out from (010). This is important in the study of rock-slides, since a section may be removed several degrees (even 30° when the optical angle is large) out of the plane of symmetry, and but small error would be made in using its value of extinction as equivalent to that on (010). It would, in that case, be only necessary to be sure that the section is really in the vertical zone, as ascertained by the parallelism of cleavage cracks. That it is near the position (010) can, of course, be proved by the absence of a well defined hyperbola in convergent light.

TABLE I.

Extinction-angle on (010).	2 V = 50°.		2 V = 60°.		2 V = 70°.		2 V = 80°.		2 V = 90°.	
	C = 62½°.	C = 77½°.	C = 62½°.	C = 77½°.	C = 62½°.	C = 77½°.	C = 62½°.	C = 77½°.	C = 62½°.	C = 77½°.
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
2	2 37	2 2	2 16	1 33	1 58	1 18	1 43	1 0	1 32	51
3	3 55	3 8	3 23	2 19	2 57	1 50	2 35	1 30	2 18	1 16
4	5 14	4 6	4 32	3 7	3 56	2 28	3 27	2 1	3 4	1 42
5	6 33	5 9	5 40	3 55	4 56	3 6	4 20	2 31	3 51	2 7
6	7 52	6 15	6 49	4 44	5 56	3 44	5 12	3 3	4 37	2 33
7	9 12	7 22	7 58	5 34	6 56	4 23	6 5	3 34	5 24	3 0
8	10 32	8 32	9 8	6 26	7 57	5 3	6 58	4 6	6 11	3 26
9	11 53	9 44	10 18	7 20	8 58	5 44	7 52	4 39	6 59	3 54
10	13 14	11 0	11 29	8 15	10 0	6 26	8 46	5 18	7 47	4 21
11	14 36	12 19	12 40	9 12	11 2	7 10	9 41	5 47	8 36	4 50
12	15 58	13 42	13 52	10 12	12 5	7 55	10 37	6 23	9 24	5 18
13	17 20	15 9	15 5	11 15	13 9	8 42	11 32	6 59	10 14	5 48
14	18 44	16 42	16 19	12 21	14 14	9 31	12 29	7 37	11 4	6 18
15	20 7	18 19	17 33	13 31	15 19	10 22	13 27	8 16	11 55	6 50
16	21 31	20 2	18 49	14 45	16 26	11 16	14 25	8 57	12 47	7 22
17	22 56	21 52	20 5	16 3	17 33	12 12	15 25	9 39	13 39	7 56
18	24 21	23 48	21 22	17 25	18 41	13 11	16 25	10 24	14 32	8 30
19	25 46	25 45	22 39	18 53	19 50	14 14	17 26	11 10	15 26	9 6
20	27 12	27 58	23 58	20 27	21 1	15 21	18 28	11 59	16 21	9 44
21	28 37	30 12	25 17	22 6	22 12	16 31	19 31	12 50	17 17	10 23
22	30 3	32 30	26 36	23 52	23 24	17 47	20 36	13 45	18 14	11 4
23	31 29	34 58	27 57	25 44	24 37	19 7	21 41	14 42	19 12	11 47
24	32 54	37 18	29 18	27 43	25 51	20 32	22 47	15 43	20 11	12 32
25	indet.	indet.	30 39	29 48	27 7	22 2	23 55	16 48	21 11	13 19

metry itself. I refer to the plane of prismatic cleavage. Table I. contains the results of calculations (repeated applications of equation 2), intended to find the value of θ, (θ'), for amphiboles when C is equal to half the cleavage angle (taken at 62½°), 2 V at successive values of 50°, 60°, 70°, 80°, and 90°, and ρ with all values of whole degrees from 2° to 25° inclusive. Thus, if any two of the three terms 2 V, ρ, or θ' be known, the third can be determined. The values of θ' are tabulated in the col-

umn headed "62¼°." This table is regarded as capable of more general application than the one published by Harker,* inasmuch as his refers only to that small class of amphiboles which have the acute optical angle situated about the axis of elasticity lying next to the vertical axis (optically positive, represented by pargasite). It will be observed that for amphiboles with small optical angle (up to 60°), any one of the three variables may be determined if the other two are known, but that, considering the instrumental errors of reading, the larger values of the optical angle cannot with much safety be determined on account of the slow variation in the corresponding angles of extinction on (010) and (110). When $2V$ is equal to 70°, ρ and θ' are for any negative species nearly equal.

The following is the similar table (Table II.) for pyroxenes, where the cleavage angle is taken at 92° 54′. It is simply a slight extension of that of Harker.†

TABLE II.

Angle of extinction on (010).	Values of θ'.			Angle of extinction on (010).	Values of θ'.		
	$2V = 50°$	$2V = 60°$	$2V = 70°$		$2V = 50°$	$2V = 60°$	$2V = 70°$
°	°	°	°	°	°	°	°
35	29¼	30½	31½	45	39	40¼	41¾
36	30¼	31¼	32¾	46	40	41½	42¾
37	31¼	32¼	33¾	47	41	42½	44
38	32¼	33¼	34¾	48	42	43½	45
39	33¼	34¼	35¾	49	43¼	44½	46
40	34¼	35¼	36¾	50	44¼	45½	47
41	35	36¼	37¾	51	45¼	46½	48
42	36	37¼	38¾	52	46¼	47¾	49¼
43	37	38¼	39¾	53	47¼	48¾	50¼
44	38	39¼	40¾	54	48½	49¾	51¼

We are not yet, however, in a position to make universal use of cleavage pieces for the purpose of finding the value of ρ. There are many

* Extinction-angles on cleavage-flakes. Mineralogical Magazine, 1894, Vol. X. p. 239.

† *Op. cit.*, p. 240.

rock-forming pyroxenes and amphiboles which, owing to the small size of the crystals or their very friable nature, it is extremely difficult, if not impossible, to cut in the directions necessary to obtain ρ and $2V$. On the other hand, good cleavage flakes are almost always to be had, and it is by the use of these that I propose the following method of finding the extinction on the clinopinacoid of an amphibole or pyroxene.

A perfectly flat cleavage piece, thick enough to give the greatest possible definiteness to the position of extinction and showing clearly marked cleavage cracks, is laid on an object-glass with the broadest face down. It is then carefully mounted on the stage of a two-circle Fedoroff table. With the vertical circle set at zero, the stage of the table is turned so as to bring the cleavage cracks of the specimen into a position parallel to the axis of the vertical circle.* This axis should be parallel to the principal section of either polarizer or analyzer. By taking the average of a number of good readings, the extinction angle is now obtained. Following this operation, the vertical circle is turned in such a direction that the plane of symmetry of the crystal is *more* oblique to the polarized ray and by an angle nearly approaching that at which the specimen would begin to slide on the object glass. I have found that 15° is a convenient amount of rotation, and that angle will be used in the following discussion. Extinction is again read in this new orientation with the greatest possible care.

We have in this way determined two special angles of extinction (θ' and θ''), corresponding to two planes in the vertical zone, which are at different angles (C' and $C'' = C' + 15°$) to (010). It is now possible in a simple way to eliminate α and β, and thus permit of the determination of ρ directly from θ' and θ''. To this end, we have the following series of transformations, which I owe to Mr. J. K. Whittemore of Harvard University.

Substituting in (2) the special values of θ and C, we have,

$$\tan 2\theta' = \frac{(\tan\alpha - \tan\beta)\cos C'}{1 + \tan\alpha\tan\beta\cos^2 C'}; \quad \text{and} \tag{3}$$

$$\tan 2\theta'' = \frac{(\tan\alpha - \tan\beta)\cos C''}{1 + \tan\alpha\tan\beta\cos^2 C''}. \tag{4}$$

Then

$$\frac{\tan 2\rho}{\tan 2\theta'} = \frac{1 + \tan\alpha\tan\beta\cos^2 C'}{(1 + \tan\alpha\tan\beta)\cos C'} = u. \tag{5}$$

* The Nachet form of the table or the simpler model by Fuess is best for the purpose.

$$(6) \qquad \frac{\tan 2\rho}{\tan 2\theta''} = \frac{1 + \tan \alpha \tan \beta \cos^2 C''}{(1 + \tan \alpha \tan \beta) \cos C''} = v.$$

$$(7) \qquad \tan \alpha \tan \beta = \frac{1 - u \cos C'}{u \cos C' - \cos^2 C'} = \frac{1 - v \cos C''}{v \cos C'' - \cos^2 C''}.$$

$$(8) \quad \frac{\tan 2\theta' - \cos C' \tan 2\rho}{\tan 2\rho \cos C' - \cos^2 C' \tan 2\theta'} = \frac{\tan 2\theta'' - \cos C'' \tan 2\rho}{\tan 2\rho \cos C'' - \cos^2 C'' \tan 2\theta''}.$$

Let $\tan 2\rho = x$, $\tan 2\theta' = x'$, $\tan 2\theta'' = x''$. We have

$$(9) \qquad \frac{x' - x \cos C'}{x \cos C' - x' \cos^2 C'} = \frac{x'' - x \cos C''}{x \cos C'' - x'' \cos^2 C''}.$$

Hence

$$(10) \quad x\,(x' \cos C'' \sin^2 C' - x'' \cos C' \sin^2 C'') = x' x'' (\cos^2 C'' - \cos^2 C').$$

Substituting the values of x, x', and x'',

$$(11) \qquad \tan 2\rho = \frac{\tan 2\theta' \tan 2\theta'' (\cos^2 C'' - \cos^2 C')}{\tan 2\theta' \cos C'' \sin^2 C' - \tan 2\theta'' \cos C' \sin^2 C''}.$$

Reducing to a form more convenient for the use of logarithms, we have

$$(12) \qquad \tan 2\rho = \frac{\tan 2\theta' \tan 2\theta'' \sin (C' + C'') \sin (C' - C'')}{\tan 2\theta' \sin^2 C' \cos C'' - \tan 2\theta'' \sin^2 C'' \cos C'}.$$

We now have an expression by means of which the extinction can be calculated even when the optical angle is not known. The theory of the same problem was elaborated by Liebisch in his discussion * of the general determination of the optical angle and of the direction of the optic axes in biaxial minerals, using sections whose crystallographic orientation is known, and on which the planes of vibration of the two refracted rays are known. Of immediate interest to us is the case in the monoclinic system where the optical plane is also the plane of symmetry, but the orientation of the two axes of elasticity is not determined. He finds the problem soluble when two sections can be employed, and this is what we practically have for optical purposes in the cleavage piece placed at two positions with respect to the incident ray from the polarizer.

But it is evident that there must be some degree of error in the instrumental readings of θ' and θ''; we have next to inquire if equation (12) is so sensitive to changes in θ' or θ'' or to simultaneous changes in both as to make any determinations of ρ by means of it valueless. By ac-

* Über die Bestimmung der optischen Axen durch Beobachtung der Schwingsrichtung ebener Wellen. Neues Jahrbuch für Min., etc., 1886, Bd. I. p. 155.

tually trying certain cases, I have found that ρ changes for small errors in θ' and θ'', but that the rate of change is not sufficiently rapid to make the method of no practical use. Indeed, the errors in ρ may in certain cases be little greater than the original errors of reading θ' and θ''. A Zillerthal actinolite may be taken as an example.

Let $C' = 62° \; 15'$, and $2V = 80°$ (an actinolite). Then $\theta' = 13° \; 27'$; and, if $C'' = 77° \; 15'$ (15° of rotation of the vertical circle), then $\theta'' = 8° \; 16'$. In the attempt to find ρ from θ' and θ'', errors of various magnitudes in θ' and θ'' were introduced as follows.

TABLE III.

	$\theta' = 13° \; 27'$ + Error of	$\theta'' = 8° \; 16'$ + Error of	ρ determined as	Error in ρ.
1	0°	+10′	14° 31′	−29′
2	0°	+20′	14° 8′	−57′
3	0°	+30′	13° 39′	− 1° 21′
4	+10′	+10′	15° ½′	+ ½′
5	+20′	+20′	15° 2′	+ 2′
6	+30′	+30′	15° 5′	+ 5′
7	+ 1°	+ 1°	15° 11′	+11′
8	+10′	−10′	16° 8′	+ 1° 8′
9	+20′	−20′	17° 28′	+ 1° 28′
10	+30	−30′	19° 2′	+ 2° 2′

The limit of error in reading extinction-angles for colorless cleavage flakes, or for those that do not display very deep absorption, may be placed at 20′. At this limit, in our example, there is seen to be an error of rather less than 1° for an error in θ'', with θ' exactly determined. When θ' and θ'' show errors of reading in the *same* direction (in the example, both plus), they may be large without making an equally large error in ρ. This is important, since any fault in the construction of the microscope will thus equally affect both readings and need not greatly influence the value of ρ, even though found by means of so sensitive an

equation. On the other hand, if θ' and θ'' vary from the truth in opposite directions, ρ quickly changes, a fact which is evident from an inspection of the expression for tan 2ρ. The table shows an error of $1° 28'$ in ρ when θ' is $20'$ too large and θ'' $20'$ too small; and again an error of $+2° 2'$ in ρ for corresponding errors of $+30'$ and $-30'$ in θ' and θ''.

If the rotation of the vertical circle had been in the opposite direction through the same angle, so as to make $C'' = 47° 15'$, the errors for cases 1, 2, 3, 8, 9, and 10 of the foregoing table would have been considerably less; those for cases 4, 5, 6, and 7, on the contrary, somewhat greater. The curves of Plates I., II., and III. show, however, that the extinction angles for each of the different amphiboles in sections cut at respective angles of $47° 15'$ and $62° 15'$ to the plane of symmetry would be nearly the same, and that the variation in the extinction-angle at $47° 15'$ in passing from one amphibole to another would be much slower than that peculiar to the $77° 15'$ position.* Hence I have chosen the latter as the more useful; in Table I., in the columns headed "$C = 77° 15'$," will be found the values of extinction angles characteristic of the same amphiboles whose extinctions on cleavage pieces have already been calculated. By the use of the whole table, a first approximation to the value of the extinction-angle on (010) can be rapidly made without the necessity of going through the rather tedious application of equation (12).

Analogous results characterize the introduction of errors into the θ' and θ'' of pyroxenes. I have chosen an Ala diopside with $C' = 43° 33'$, $2V = 59°$, and $\rho = 36°$. Then, revolving the cleavage-face (110) 15° away from (010), we have $C'' = 58° 33'$. θ' was calculated to be $31° 16'$, and $\theta'' = 26° 8'$. Introducing arbitrary errors in θ' and θ'', we obtain the results of the accompanying Table IV.

Generalizing from the two error tables, supplemented by the inspection of equation (12), we can reach certain conclusions regarding the influence of instrumental errors. Equation (12) is least sensitive for errors in θ' and θ'' when these are either both plus or both minus and equal or nearly equal. When equal, ρ can be more accurately determined than by direct measurement on a section in the plane of symmetry (given the use of the same microscope in both cases, as well as equal thicknesses, absorption, etc. for the cleavage piece and cut section).

* It is, of course, evident that *both* readings (at $47\frac{1}{4}°$ and $77\frac{1}{4}°$) can be taken on the same cleavage piece; and also that amounts of rotation other than 15° may be advantageously employed. Experiment shows that the cleavage piece will not slide on the object-glass even at an angle of 20°, and thus θ may be determined for the $42\frac{1}{4}°$ and $82\frac{1}{4}°$ positions.

TABLE IV.

	$\theta' = 31^\circ 16'$ + Error of	$\theta'' = 26^\circ 8'$ + Error of	ρ determined as	Error in ρ.
1	0°	10′	35° 46′	−14′
2	0°	20′	35° 32′	−28′
3	0°	30′	35° 18′	−42′
4	10′	10′	36° 8′	+ 8′
5	20′	20′	36° 18′	+18′
6	30′	30′	36° 27′	+27′
7	1°	1°	36° 57′	+57′
8	10′	−10′	36° 36′	+36′
9	20′	−20′	37° 15′	+1° 15′
10	30′	−30′	37° 52′	+1° 52′

When the errors of θ and θ'' are unequal, the resulting error in ρ is more significant and is most unfavorable when the errors of reading the extinction in the two positions are of opposite sign. When equal numerically, the error in ρ for actinolite and diopside is about four times that made by directly reading the extinction on a plate cut parallel to (010). The necessity for accurate measurement of θ' and θ'' is evident. In actual practice, moreover, several independent determinations of ρ should be carried out and an average taken to secure the safest results.

Two examples may suffice to show the kind of results obtained by the author in the application of the method here outlined. The Philipstad hornblende already referred to was studied with reference to the extinction on (010), first by the use of two carefully oriented sections made by M. Werlein of Paris, then by the use of cleavage pieces. The former gave an extinction on (010) of 15° 5′ (white light). Extinction was then read on a cleavage flake and found to be 20° 53′, as the result of averaging many readings. This flake was then turned into the position where the plane perpendicular to the ray of light from the polarizer made an angle of 77½° with the plane of symmetry of the crystal. Ex-

tinction was read in this position against the cleavage trace, at an angle with the latter of just 20° (average of ten readings). Substituting this value and the value of extinction on (110) in equation (12), I obtained 15° 3′ as the corresponding value of ρ. This very close correspondence with the determination of ρ by the use of the oriented sections is not less than accidental, but the example clearly shows that cleavage pieces may be made to yield information concerning the value of extinction on the plane of symmetry as useful for practical purposes as that derived from a section in that plane.

A second example was found in a hornblende, which was given me for examination by Professor J. E. Wolff of Harvard University. It occurs associated with much pyroxene and biotite in the classic coarse theralite of Theralite Peak in the Crazy Mountains. Optical study of the hornblende in the numerous slides which have been made of the rock is difficult, on account of the scarcity of the mineral in large individuals. It would be quite impossible to make oriented sections even if the grains could be freed from the much more abundant pyroxene, with which they are commonly intergrown. Apart from the absolute small amount of the hornblende present in the rock and from the fact of intergrowth with another silicate, this seemed to be a particularly unfavorable case for the application of our method, in that the absorption is strong, and errors in θ' and θ'' should appear rather larger than characterize readings on such an amphibole as Zillerthal actinolite, for example. The rock was pulverized and, after some search, suitable cleavage pieces were discovered in the powder, and manipulated as in the last example. This time, the curve of extinctions was examined on four points besides that at the position (010); namely, at the positions, 42½°, 47½°, 77½°, and 82½°. Extinctions were read for these at respective values of 29°, 29° 30′, 31°, and 30°. The cleavage position gave 34°. The average value of ρ now determined by substituting the readings in the general equation is 28° 5′. Now, I was fortunate enough to find in one of the thin sections a longitudinal section of the hornblende, evidently in the vertical zone since the cleavage cracks were rigorously parallel to one another, and very near the plane (010), inasmuch as there was practically no trace of a hyperbola in convergent light. Careful reading of the extinction afforded an astonishingly close approximation to the value of ρ just determined, viz. 28°. It is possible that the true angle is half a degree or more greater or less than that, but the calculated value is in any case near that observed in the rock-slide. It may be noted in passing that this is a rather remarkable hornblende, from the fact that its extinction angle is

abnormally high; the optical angle is also unusual, for calculation shows that it must be about 55°. Unfortunately, for reasons specified above, the mineral cannot be separated and chemically analyzed.

In the process of working out these illustrations, the author has come to the conclusion that, with the proper safeguards, the method can be safely applied to the amphiboles in general; and that the pyroxenes can be similarly treated. It may thus prove to have more than mere theoretical interest.

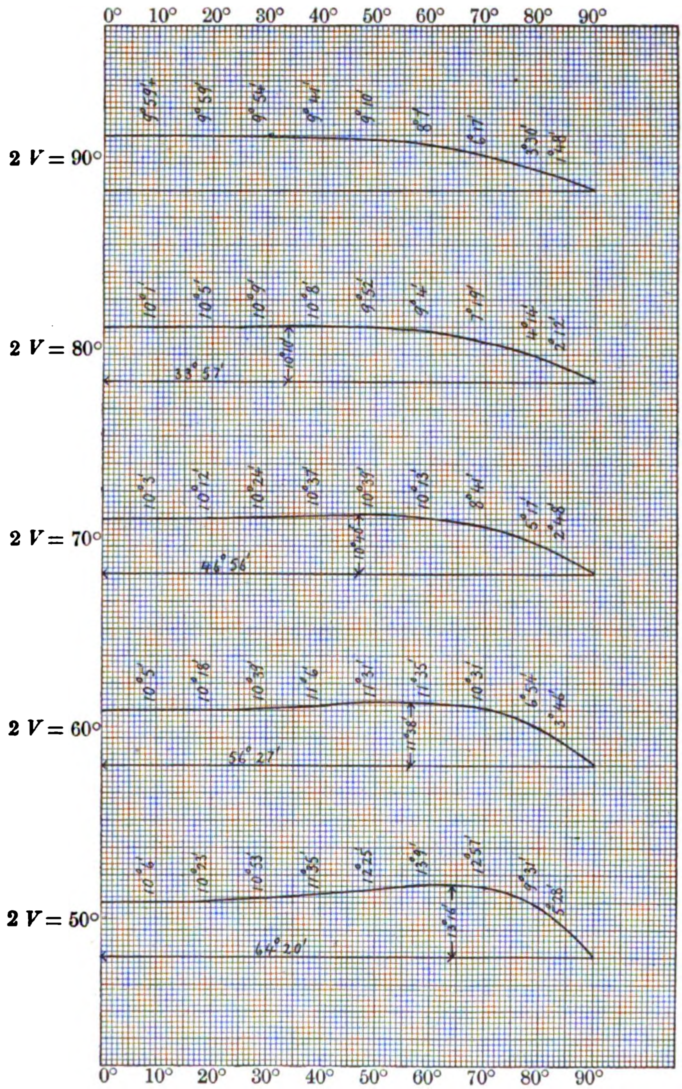

PLATE I. — Showing the curves of extinction in the vertical zone of Amphiboles for which the extinction on (010) is 10° and the optical angle is 50°, 60°, 70°, 80°, or 90°. The abscissa represents the amount of rotation of a plane in the zone away from the plane of symmetry. The ordinate is the corresponding angle of extinction for that position of the movable plane. The position and amount of maximum extinction are represented by arrow-heads. The values of extinction for 10° intervals in the zone are entered in the diagram.

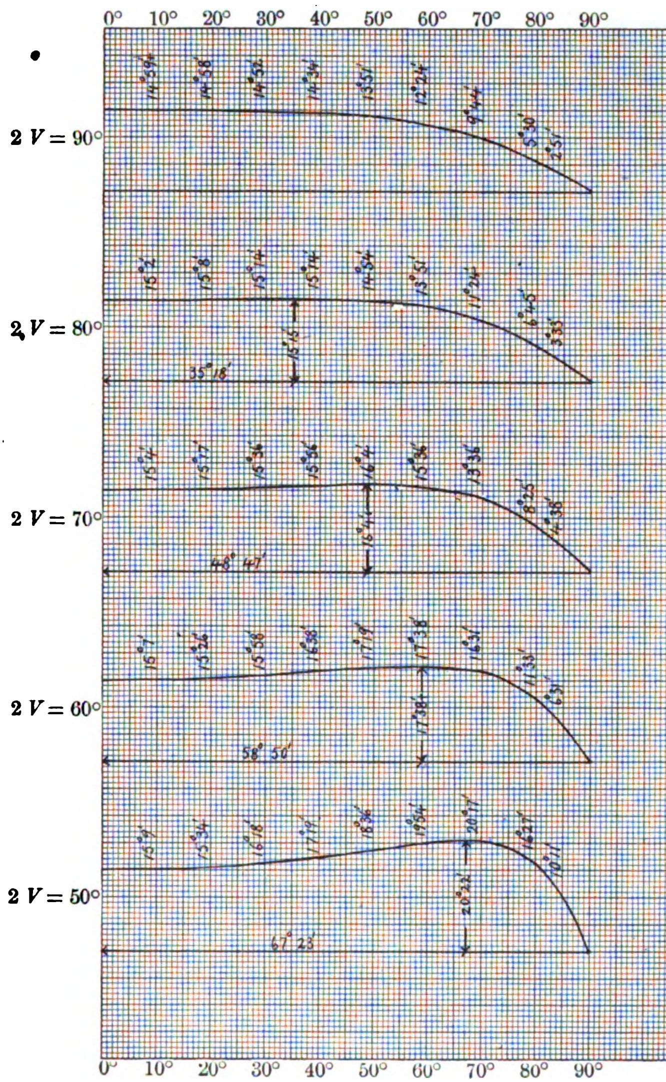

PLATE II. — Showing curves formed on the same plan as those of Plate I. The extinction on (010) is here 15°.

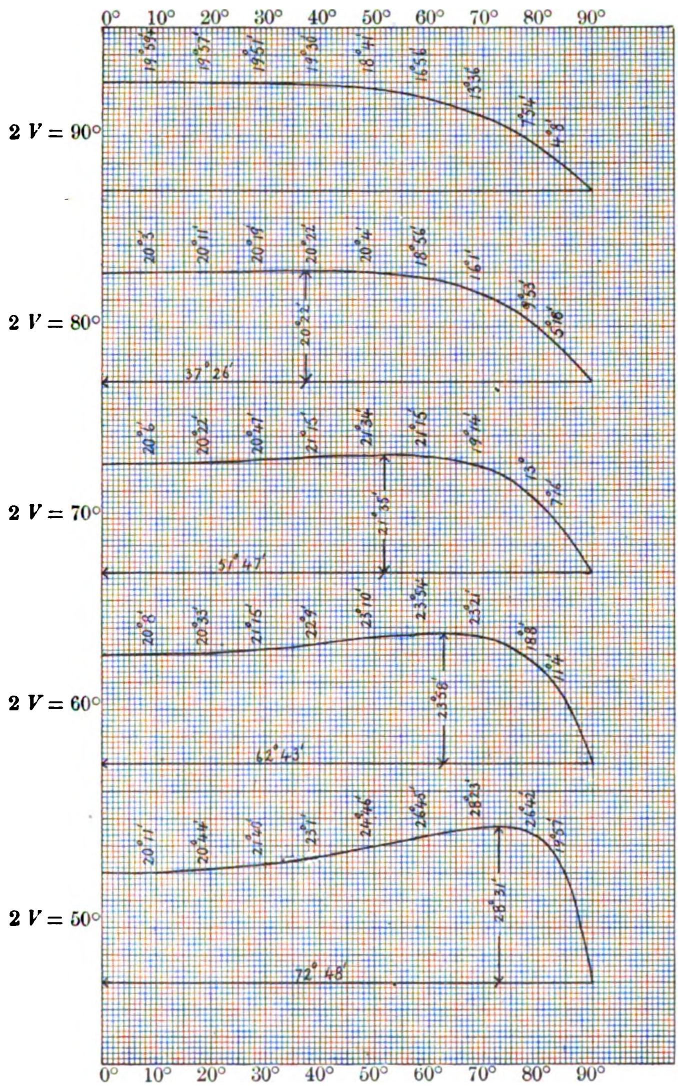

PLATE III. — Showing curves formed on the same plan as those of Plate I. The extinction on (010) is here 20°.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF NICKEL.

SECOND PAPER. — THE DETERMINATION OF THE NICKEL IN NICKELOUS BROMIDE.

BY THEODORE WILLIAM RICHARDS AND ALLERTON SEWARD CUSHMAN.

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A REVISION OF THE ATOMIC WEIGHT OF NICKEL.

SECOND PAPER. — THE DETERMINATION OF THE NICKEL IN NICKELOUS BROMIDE.

By Theodore William Richards and Allerton Seward Cushman.

Presented October 12, 1898. Received December 29, 1898.

In a recently published investigation upon the atomic weight of nickel we gave three series of results, depending upon the ratios of silver and of argentic bromide to nickelous bromide.* These led us to the conclusion that the atomic weight in question could not be far from 58.69 if oxygen is 16.000. Since however no single method is ever convincing, and since the results above mentioned did not represent all that might be done even with one method, it was evidently advisable to pursue the matter to a more definite conclusion. Accordingly, we determined to continue the work with a twofold object in view: first, to study further the preparation of pure material, and secondly, to complete the analysis of nickel bromide in such a way as to *determine directly the amount of nickel as well as the amount of bromine in the salt.* No surer test of a quantitative result than such a complete analysis is known. The careful study of all the conditions and results has led us to the conclusion that the preparation of pure nickelous bromide is an unusually difficult problem; but the problem has been so nearly solved that we know exactly the precautions and corrections necessary to make this substance serve as an accurate basis for the determination of the atomic mass of nickel. In the light of this later knowledge we find that the results of the last paper need a slight correction, but it is satisfactory to note that the change amounts to not much over one unit in the second decimal place of the atomic weight.

While carrying out the work, we had continually in mind the various controversies which have arisen over the atomic weights of nickel and

* These Proceedings, XXXIII 97.

cobalt; and feeling that the "Gnomium" question raised by Krüss and Schmidt had never been conclusively laid at rest, we naturally dwelt especially upon it. Unfortunately, one cannot enter into a discussion of this subject without directly antagonizing many views which have been expressed on one side or the other; but of course the following results are recorded solely in the interests of truth, without controversial bias.

The balance and weights used in the work described were the same as those described in the former paper. The weights were re-standardized, with results very similar to those found a year before. All weighings of nickelous bromide were reduced to the vacuum standard by the addition of 0.114 milligrams per gram to the observed weight. The specific gravity of nickel (about 8.7) is so near the specific gravity of brass (8.4) that the correction of the nickel to the vacuum standard is less than one part in a hundred thousand, hence it may be omitted.

Experiments concerning the Purity of the Materials.

The purification of our nickelous material has already been described at length.* Most of the work described below was done with nickel which had been purified by Mond's process and many subsequent operations (Sample III.†), but two analyses were made with a somewhat less pure sample (No. II.†) made from commercial material. Since we had proved that further protracted treatment produced no effect on the combining weight, evidently these specimens were quite pure enough for our purpose.

Krüss and Schmidt used glassware in their preparation work, therefore it seemed worth while to make an exact observation of the well known danger involved in this practice. To this end two very carefully treated specimens of spongy nickel were prepared, one having been made wholly in platinum, and the other wholly in the best Bohemian glass, which had been thoroughly steamed. The former of these preparations, which was supposed to be absolutely pure, left upon sublimation as bromide in a stream of bromine vapor only a very minute siliceous residue. The specimen of nickel which had been prepared in glass vessels was totally different in appearance from the one prepared in platinum; instead of being metallic and coherent, it was black and powdery. Upon the conversion of about ten grams of this dark powder into nickelous bromide, a beautifully iridescent voluminous residue, weighing about five milligrams and consisting mainly of silica, was left in the boat. Evi-

* These Proceedings, XXXIII. 102. † Ibid., 105.

dently this silica had prevented the cohering or "sintering" of the metal during its original reduction from the oxide, and hence caused the pulverized state of the impure metal, — a fact which is interesting as showing the great change in properties produced by a small amount of impurities.

These two experiments emphasize the well known facts that glass is wholly unsuitable for accurate work, and that material prepared even in platinum is extremely difficult to render wholly free from silica, unless it is vaporized.* While however our purest *nickel* sometimes contained traces of silica, the *bromide* prepared from it by sublimation was undoubtedly as free as possible from this impurity. Further light upon this question will be given in a following paper upon cobalt.

Although a possible contamination with silica was thus little to be feared, some other constituents of glass or porcelain were much more dangerous. All the material actually used in our analyses had been prepared wholly in platinum vessels at every stage excepting at the very end, when it had been sublimed in a porcelain tube. Obviously this tube might be attacked by the hot mixture of hydrobromic acid, bromine, and nickelous bromide vapor; but since nothing beside sodic bromide would probably sublime with the nickelous salt, and the "equivalent" of sodic bromide is almost equal to that of nickelous bromide, the slight impurity could produce no important effect upon our last year's work. This was realized at the time; and the discovery of the presence or absence of this error was one of the prearranged objects of the present paper. Since the work recorded below was completed, Professor Winkler, by a kind personal letter as well as by a recent article, wisely called attention to this flaw; and it will be seen that his objection had been both substantiated and answered before he wrote about it.

The easiest method of detecting sodic bromide in nickelous bromide is obviously to reduce the latter and then to extract the former with water from the spongy metal. Moist hydrogen easily divorces the halogen from its none too stable metallic union at a temperature of not much over 300°, at which temperature sodic bromide is essentially non-volatile. In this way repeated experiments showed that all our nickelous bromide had contained on the average not far from one tenth of one per cent of sodic bromide. The particulars concerning the determination of this serious impurity naturally form an essential point in the method of analysis of the nickel salt, hence they will be found later under that head.

* Compare Stas's "Untersuchungen" (Aronstein), pp. 269 and 279.

The presence of an unreduced bromide was first detected by Mr. Baxter in the course of his work on cobaltous bromide, and some interesting details involved in its discovery will be recorded in the paper upon that subject. The amount present varied with the temperature used in the sublimation, but was otherwise surprisingly constant. The concurrent sublimation of the two salts is undoubtedly similar to the distillation of organic substances with steam, sodic bromide possessing a small constant vapor-tension at the constant temperature of about 900° used in the sublimations.

After the completion of a series of reductions of nickelous bromide containing this impurity of sodic bromide, a final attempt was made to obtain the salt of nickel in a state of absolute purity. We expected that platinum would be attacked by the mixture of bromine vapor, hydrobromic acid, and nickelous bromide, which exists in the red-hot tube during the sublimation of the salt, but platinum is the last resort in cases of this kind. In order to sacrifice as little of the precious metal as possible in our desperate experiment a large porcelain tube was lined with platinum foil,* and inside of this was placed a platinum boat containing the metal to be converted into bromide. In each of two separate specimens of nickelous bromide made in this apparatus merely a trace of sodium was found, but unfortunately enough platinum was present to render the results valueless. They are not included in the tables below. Only a small strip of the foil was injured, the very hot parts and the cool parts being alike untouched. After these experiments we abandoned the attempt to prepare absolutely pure nickelous bromide, and returned to the use of the porcelain tube for the sublimations; for sodium is an impurity much more easily weighed than platinum, under the circumstances. The only method of obviating the difficulty would have been to use a tube of nickel for the sublimation; but the obtaining and moulding of a large amount of the metal in a perfectly pure state promised to be so troublesome that we have not yet attempted this improvement.

The arrangement for supplying and purifying the large volumes of hydrogen needed in this research was gradually evolved from the simple form used in the first experiments to an elaborate piece of apparatus which will be described in detail in the paper upon cobalt.

The preparation of bromine and of the other materials has been de-

* This idea was suggested by Professor H. B. Hill. Compare also Penfield, Zeitschr. Anorg. Chem., VII. 22.

scribed in sufficient detail in other papers,* so that no further words need be wasted upon these points. It is almost unnecessary to state that in these simple operations no loophole was left open through which an error might creep in to destroy the value of the more difficult undertaking before us. We are indebted to the Cyrus M. Warren Fund for Chemical Research in Harvard University for some of our more expensive pieces of apparatus.

The Method of Analysis.

At first many attempts were made to determine nickel by electrolysis, with the hope that nickelous bromide might be analyzed in this simple and direct fashion. In order to test the method, weighed amounts of the purest spongy metal were dissolved and reprecipitated electrolytically. The spongy metal had been prepared by boiling the purest platinum-made ammonio-nitrate with much water, igniting and reducing the precipitate with pure ammonia, and heating the metal in a vacuum. The weight of nickel deposited by electrolysis always exceeded that of the pure nickel taken, hence the electrolytic method was abandoned as unsuitable for work of the highest accuracy. The excess of weight, which was noticeable even when the film was heated to 120° before weighing, and often exceeded two tenths of one per cent when it was dried at 50° after the method of Winkler,† was traced to inclusion of mother liquor between the film and the dish, and to the probable presence of occluded hydrogen in the nickel.‡ Since the deposit was beautifully metallic and coherent in appearance, one might well have expected a better result. It is possible that these observations may help to explain Winkler's high values for the atomic weight of nickel and cobalt, since he used the electrolytic method. On the other hand, the *spongy* metal which had been used in our experiments was probably purer than that prepared in any other way, for solid impurities had been rigorously excluded, and the traces of gas present had been pumped out.

These preliminary experiments showed that the best method of determining the amount of nickel in the bromide would be to reduce it in a stream of hydrogen, provided that the reduction could be accomplished without the loss of any of the bromide by volatilization. Following in the footsteps of Mr. Baxter's work with cobalt, it was found that moist

* These Proceedings, XXXIII. 106 *et seq.*

† Zeitschr. Anorg. Chem., IV., 22.

‡ Raoult, Compt. Rend., LXIX. 826; Böttger, Dingler's Polytech. Journ., CCL. 80 (1871).

hydrogen answered the purpose; for the temperature at which the reduction takes place is so low that no trace of nickel was found outside of the boat which originally contained the bromide, if a rapid current of the gas was maintained. It is obvious that according to the law of mass-action, the presence of a large proportion of hydrobromic acid resulting from the reduction would tend to prevent the desired reaction, and hence to facilitate the undesired sublimation; therefore a large excess of hydrogen must be present. Of course the hard glass tube used for this process was always afterwards treated internally with nitric acid, and the liquid was examined with minute care for traces of nickel.

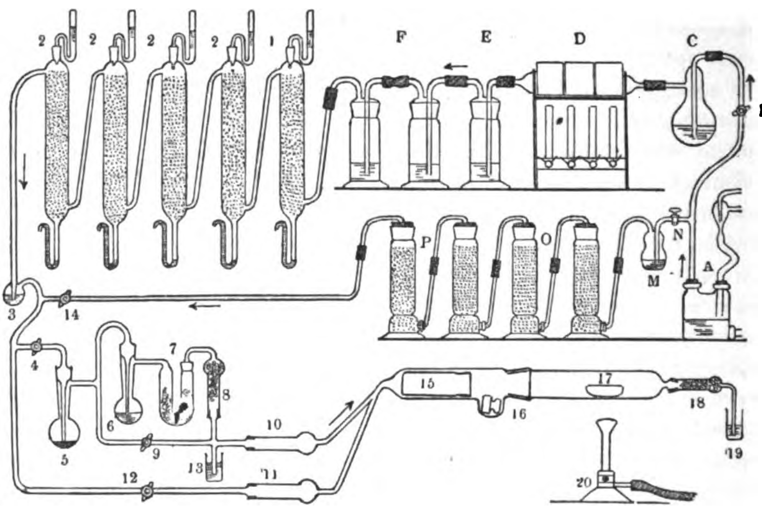

Fig. 1. Apparatus for igniting Nickelous Bromide in any desired Mixture of Gases.

The use of rubber was confined to the first part of this train, where it could do no harm (A B C D E F and A M N O P).

The nickelous bromide to be analyzed was contained in a platinum boat, and the method of drying and weighing it was in every respect the same as that described in detail in the previous paper upon this subject. After having been weighed, the boat was carefully placed in a hard glass tube, in which the bromide was cautiously reduced to the metal. When the reduction was completed and the apparatus had just cooled, the boat and its contents were returned to their weighing bottle, where they were enclosed in an atmosphere of dry air. The weight of the residue was

found after half an hour, and then at the end of many hours. Since the boat was cool before having been introduced into the bottle, two successive weighings thus made never differed from one another by amounts beyond the limit of error of weighing. Spongy nickel evidently does not oxidize in dry air.

It is obviously a matter of great importance to discover whether or not the material prepared in this way contains weighable amounts of occluded hydrogen. According to the experiments of Neumann and Streintz* who worked with reduced metals, two cubic centimeters of the gas were occluded by each gram of spongy nickel. This amount would alter the observed atomic weight by only about the fortieth of one per cent; but since we are aiming at even greater accuracy, the matter should evidently be probed to the bottom.

In the first place, carefully weighed nickel remaining from one of the analyses recorded below was ignited in a Sprengel vacuum at perhaps 550°. For fear of losing some sodic bromide a higher temperature could not be employed. No appreciable loss of weight occurred and no gas was evolved during this process, which was repeated with several specimens; hence there seemed to be good reason to believe that no hydrogen was occluded by the metal in our experiments. In order to prove the matter, one and a half grams of spongy nickel reduced from the bromide and allowed to cool in hydrogen was oxidized by heating in a current of dry air, which was subsequently passed over red hot cupric oxide, and through a carefully weighed tube containing phosphoric oxide. Since the absorption tube did not gain in weight, no water could have been formed during the combustion, and hence no hydrogen could have been occluded.

Treated in exactly the same way, four grams of nickel prepared by the reduction of the *oxide* yielded about three milligrams of water, or about half the amount found by Neumann and Streintz. This agreement is sufficient to show that these investigators were not mistaken in their conclusions, and that the permeability of nickel is enormously modified by minor circumstances.

Is the presence of the sodic bromide, otherwise so objectionable, the agency which prevents the occlusion in our case, or does the volatility of nickelous bromide allow its metal to be deposited in a form more coherent than that remaining from the oxide? The attempt to answer these

* Monatshefte für Chemie, XII. 640 (1891). Berichte der d. ch. Gesell., XXV., 1872.

questions experimentally would be far from uninteresting, but it is sufficient for the present purpose to prove in the manner described above that nickel treated as we have treated it in the following determinations does not occlude an important amount of hydrogen, and does not oxidize in dry air. Confirmatory evidence will be found in the paper upon cobalt which follows.

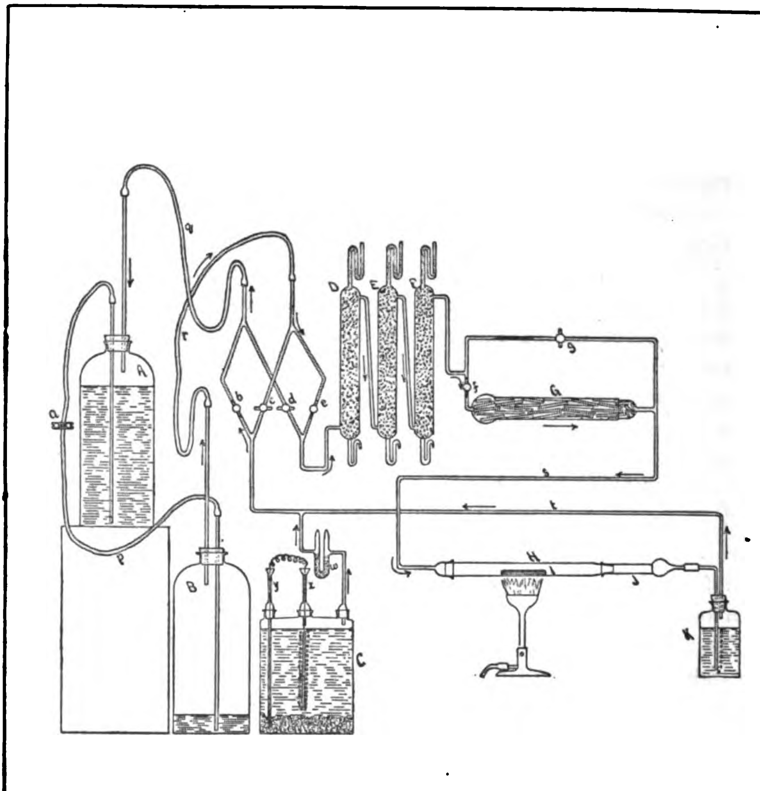

FIG. 2. APPARATUS FOR REDUCING THE BROMIDE.

Before it was possible to use the data thus obtained for the calculation of the desired atomic mass, the weight of sodic bromide existing as impurity within the spongy metal must obviously be found. Accordingly the residue was digested with successive portions of pure water in a platinum dish, and the bromine in the filtrates was precipitated and weighed as

argentic bromide. Since the spongy metal (after slow solution in very dilute nitric acid in a platinum dish) was found to contain no bromine, it is safe to infer that all the soluble impurity had been leached out by the water. This process was repeated with every analysis, the result being always the same. From the weight of argentic bromide thus obtained, the weight of the impurity of sodic bromide was alculated, and when this quantity was subtracted from both the original weight of the nickelous bromide and the weight of the spongy metal, data suitable for the calculation of the atomic mass were obtained.

In order to show that this method of correcting the results is really exact, it is necessary to prove, first, that no impurity other than a bromide remains behind in the nickel, and secondly, that no impurity beside sodic bromide is dissolved by the water. The first point has been already partially considered; we have shown that silica at least was absent.* Since silica was the only non-volatile and insoluble acid likely to have been present, and all the bromine had been dissolved out by water, the only probable impurities were other metals capable of being reduced from their bromides by hydrogen. But these, even if they had been present in unsuspected and undiscoverable traces, could have exercised no appreciable effect upon the atomic weight unless their equivalents were widely different from that of nickel. Hence this possibility of error need cause no anxiety. Finally, it has been already stated that no weighable amount of hydrogen was ever found in the metal, hence we are justified in the assumption that the washed out spongy nickel is a safe material upon which to base the calculation of the atomic mass in question.

The question as to the purity of the sodic bromide in the wash-waters was a matter less easily settled. Careful qualitative and quantitative analysis of the liquid were alone capable of deciding the point, and with only infinitesimal amounts of material such elaborate examination was difficult. To make a very long story short, nothing was found in any of the wash-waters beside sodium, bromine, nickel, and in some of the earlier analyses traces of sulphuric acid. This last impurity may have crept in from the air during the evaporation of the aqueous solutions, or possibly from the towers used for drying the nitrogen and air. In the later analyses sulphuric acid was not used in these towers, and was proved to be absent from the nickelous bromide. As its amount was in any ease very small, we felt justified in neglecting it as one neglects an infinitesimal of the second order in the course of mathematical reasoning.

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* See p. 328.

On the other hand, the amounts of nickel in the wash-waters were distinctly weighable, and not to be overlooked. That it was nickel, and not a new metal, there could be no room for doubt, for it gave a black sulphide and a green sulphate, the characteristic pink coloration with potassic thiocarbonate, as well as a beautiful rose-colored flame test, which we have found to be characteristic of nickelous halides. Since the nickel salts are much more easily reduced than those of cobalt (see the next paper), it is harder to obtain a satisfactory flame test in the former case than in the latter. Only when both salts and gas are *dry*, and the vaporization proceeds in the inner flame, are the best results to be obtained. We have found no reference to this flame reaction of nickel halides in chemical literature,* and one cannot but believe it to have been unknown to Krüss and to Winkler at the time of one of their disputes.†

The question now arises, Whence came this nickel? Was it occluded as nickelous bromide in the interior of crystals of sodic bromide, and thus protected from reduction, or was it dissolved as hydroxide from the spongy metal? The large quantity of nickel present seemed to overthrow the former alternative, but the possibility of the latter is emphatically denied by Winkler,‡ and rejected after some hesitation by Krüss.§ Since the equivalent of nickelous bromide is very near that of sodic bromide (109.3 : 103), and the impurity was calculated from the amount of bromine present, the point has no important bearing on the immediate problem; but nevertheless it is always interesting to settle a mooted question of this sort.

Winkler's experiments were made with coherent nickel coated on the inside of a platinum dish, while Krüss's experiments were made with spongy metal in porcelain vessels. The former found no trace of any substance in the water in which his nickel had been digested, while the latter found a large residue (most of which must have come from the porcelain), and hastily ascribed this residue to the presence of an unknown element. It

* Vogel, Spectral Anal. irdischer Stoffe, pp. 246, 262.

† Krüss and Schmidt, Zeitschr. Anorg. Chem., II. 249; Winkler, Ibid., IV. 17. Krüss observed the appearance of a pale rose-colored flame during the ignition of his nickel in a Rose crucible in hydrogen, accompanied with a loss of weight. If the hydrogen was *dry*, and especially if, as is often the case, it contained traces of hydrochloric acid, minute traces of nickelous chloride might have been sublimed and have caused this phenomenon, which Krüss ascribed to "gnomium" and Winkler ascribed to potassium. This question is worthy of further attention.

‡ Winkler, Zeitschr. Anorg. Chem., IV. 12.

§ Krüss, Zeitschr. Anorg. Chem., II. 238.

is not at all impossible that, in spite of the well known permanence of the smooth bright surface of a nickel-plated object, the spongy metal reduced by hydrogen might be easily oxidized and dissolved.* The difference in this respect between polished iron and the same metal reduced by hydrogen is well known. Hence Winkler's experiments prove nothing with regard to the behavior of finely divided nickel. The position of nickel on the positive side of hydrogen in the electro-chemical series leads one to expect that it must behave as zinc and iron do, although to a less degree.†

In order to decide the matter so far as the present work is concerned, we sought to determine experimentally, first, if the purest water is capable of acting on the purest nickel, and secondly, if the hydroxide thus formed is slightly soluble in water. To settle the first point, some very pure reduced nickel was thoroughly washed with water, and then digested at 20° for some time with repeated portions of water just purified. In every case nickel could be found in the filtrate, both by means of potassic thiocarbonate and by evaporation to dryness. Many repetitions of the experiment with new samples of metal brought always the same result. It is quite possible that galvanic action hastened this oxidation, for of course the nickel was contained in a platinum dish. Since Winkler's dish was evenly coated, the water probably did not touch the platinum in his case, and hence this possible cause of acceleration was absent; but the difference between the smooth surface and the finely divided surface alone is amply sufficient to explain the difference in the speed of the reaction.

It will be remembered that Krüss, in one of his experiments, digested a mass of nickel for a year on the steam bath with water, and obtained a white residue which was the chief basis of his alleged discovery. Our work shows that this residue must have contained not only dissolved porcelain, but also enough nickel to yield the black sulphide, the pale green color, and the electrolyzed metal which led Krüss so far astray.

* It is a peculiar household fact that cold water faucets plated with nickel are usually less brilliant than their hot water comrades; this difference may well be ascribed to the slow action of condensed water, even upon polished nickel. The greater tendency to rust shown by cobalt may well be due to the fact that in its case the hydroxide is converted into a higher state of oxidation immediately upon being dissolved, thus giving opportunity for the solution and hence for the formation of more hydroxide. In the case of nickel the thin permanent film of $Ni(OH)_2$ probably protects the metal, although its solubility may be no less than that of $Co(OH)_2$.

† See a paper entitled "Autoxydation," by R. Ihle, Zeitschr. phys. Chem., XXII. 114.

It is clear that, since no acid was present in the water, *the nickel must have been dissolved in the form of hydroxide.* In none of our experiments with the purest metal did the solution give an alkaline reaction with phenol phthaleïn, hence hydroxyl ions must be absent, and the hydroxide must be dissolved in a colloidal form. The alkaline reaction sometimes observed by Krüss and Winkler must have been due to impurities, as Winkler pertinently suggests. Traces of alkali would surely be found in nickel oxide precipitated in glass vessels, even when mercuric oxide was used as the precipitant.

Nickelous hydroxide, precipitated by alkali and thoroughly washed, possesses at least as great solubility as the hydroxide which is formed by the slow oxidation of nickel. Upon suitable electrolysis, fifteen cubic centimeters of such a *cold* solution yielded 0.00062 gram of nickel, while another similar portion yielded 0.00057 gram, or about 0.04 gram per litre. Since the solubility is a colloidal one, its limit is indeterminate; hence no elaborate attempt was made to discover its exact amount. It is well known that the presence of other salts in the solution diminish this kind of solubility, but the small amount of sodic bromide present in this case was insufficient to produce any considerable effect. Undoubtedly the fact that the solubility is colloidal and uncertain is responsible for the conflicting statements of the various authorities and handbooks.*

This solubility of nickelous hydrate is the circumstance which obliged us to determine the residue of sodic bromide through argentic bromide, instead of simply by evaporating the wash-waters poured off from the nickel and weighing the residue. This necessity is made clear by the following table.

No. of Anal.	Weight of Nickel.	Weight of Residue extracted by Water and dried at 105°.	Weight of AgBr.	Weight of NaBr calculated from AgBr.	Weight unaccounted for.
	grams.	grams.	grams.	grams.	grams.
6	0.805	0.00330	0.00410	0.00225	0.00105
7	1.488	0.00895	0.01398	0.00767	0.00128
8	0.607	0.00400	0.00568	0.00311	0.00089

In order to prove that this large percentage of unexplained residue

* Finkener (Handbuch der Anal. Chem. von Rose, 6te Auflage von Finkener, II. 186); Busse (Zeitschr. Anal. Chem., XVII. 60); Fresenius (Quant. Anal., 1877-1887, II. 893, 828); Roscoe and Schorlemmer (A Treatise on Chemistry, Vol. II. Part II. p. 149); Winkler (*loc. cit.*); Krüss (*loc. cit.*); etc. Temperature is a circumstance which produces great effect on this kind of solubility, heat being apt to coagulate the dissolved material.

consisted chiefly of nickelous hydrate, two more determinations were made with new material. Since enough data for the atomic weight had been obtained, and time pressed, the bromide of nickel was not weighed in the first place. In these analyses the *nickel* dissolved as hydroxide was also weighed.

Weight of Residue obtained, dried at 105°.	Argentic Bromide found.	Nickel deposited electrolytically.	Sodic Bromide calculated.	Nickelous Hydroxide calculated.	Total calculated Weight of Residue.	Weight unaccounted for.
grams.	grams.	grams.	grams.	grams.	grams.	grams.
0.00925	0.01405	0.00092	0.00770	0.00146	0.00916	0.00009
0.00480	0.00630	0.00084	0.00345	0.00133	0.00478	0.00002

Besides this quantitative proof that the residue consisted of nothing but sodic bromide and nickelous hydrate, many qualitative analyses had shown the absence of lime, alumina, silica, and even potash, from the solution poured off from the reduced nickel. Traces of sulphuric acid were found, as has been said, only in the first specimens.

In the light of all these results, no doubt seemed to remain as to the proper mode of correcting the direct gravimetric results of the reduction. Obviously the weight of the sodic bromide must be subtracted from the weights of both the nickelous bromide and the metal formed from it by the action of the hydrogen; for the salt existed in each. On the other hand, the nickelous hydroxide was simply to be neglected; for this substance was formed after the last weighing had been finished. The temperature used for the reduction was so low that no sodic bromide was vaporized; at least none could be found in the cooler parts of the reduction tube.

Analyses 5 and 6 were made with nickelous bromide of the grade of purity represented by the numeral II. in the former paper, while all the others were made with that labelled III., which had been made through the carbonic oxide process. The headings of the various columns will show with sufficient clearness the meanings of the figures given below.

In this series of results, the lowest is 58.696, while the highest is 58.719, a variation ± 0.012 from the mean. Adding all the determinations together, 24.31725 grams of nickelous bromide yielded 6.52286 grams of pure washed nickel and 0.02778 gram of sodic bromide, calculated from 0.0507 gram of argentic bromide. These two weights, taken in connection with the amount of bromine found a year ago, furnish a

THE ATOMIC WEIGHT OF NICKEL.

FOURTH SERIES. — O = 16. — RATIO = $NiBr_2 : Ni$.

No. of Anal.	Sample.	Weight of Nickel Bromide in Vacuum.	Weight of Nickel in Vacuum.	Weight of Sodium Bromide to subtract.*	Weight of Nickel Bromide corrected.	Weight of Nickel corrected.	Atomic Weight of Nickel.
		grams.	grams.	grams.	grams.	grams.	
1	III.	2.83610	0.76366	0.00285	2.83325	0.76081	58.705
2	III.	3.21908	0.86641	0.00283	3.21625	0.86358	58.696
3	III.	2.31578	0.62431	0.00337	2.31241	0.62094	58.703
4	III.	2.88330	0.77707	0.00377	2.87953	0.77330	58.710
5	II.	2.29843	0.61872	0.00193	2.29650	0.61679	58.719
6	II.	2.99118	0.80497	0.00225	2.98893	0.80272	58.714
7	III.	5.52058	1.48823	0.00767	5.51291	1.48056	58.716
8	IIIa.	2.25280	0.60726	0.00311	2.24969	0.60415	58.710
						Average	58.709

complete analysis of the best nickelous bromide which we were able to prepare. It must be remembered that 15.51556 grams of the halide contained, according to two different methods, 11.34985 and 11.34979 grams of bromine.

COMPLETE ANALYSIS OF NICKELOUS BROMIDE.

			Per cent.
Nickel		=	26.824
Total Bromine = 73.151% =	Bromine combined with Nickel	=	73.062
Total Impurity = 0.114% =	Bromine actually found in impurity	=	0.089
	Sodium	=	0.025
	Total	=	100.000†

* The weights of argentic bromide from which the sodic bromide was calculated were respectively 0.00520, 0.00516, 0.00615, 0.00687, and 0.00352 grams in analyses 1, 2, 3, 4, and 5. For analyses 6, 7, and 8, the figures are given on p. 338.

† As has been detailed, some of the earlier preparations contained traces of sulphuric acid in addition. Since this is not taken into account in the average, the sum given is slightly too small, and is perhaps deceptive in its accurate showing. The flaw was eliminated as soon as it was discovered, therefore we had no means

It has been already pointed out that this impurity of $\frac{1}{40}$ per cent of sodium would make no difference in last year's results if the "equivalent" of sodium equalled that of nickel. Since, however, it is somewhat less, slightly too much argentic bromide was obtained last year, and the atomic weight of nickel appeared lower than it really is. Assuming the amount of impurity to have been the same in last year's preparation as in this, 0.015 should be added to the atomic weight, in order to correct this error. The results of the four series, which represent the sum and substance of the present research, are then as follows. Ratios (*e*) and (*f*) were obtained by cross-reckoning from the earlier ratios. The reason for thus restating the results is because this restatement uses the weight of the nickelous bromide only as a constant, and not as a basis of calculation.

		Atomic Weight of Nickel if O = 16.000.
(*a*)	Preliminary: $2\,AgBr : NiBr_2$	[58.695]
(*b*)	$2\,AgBr : NiBr_2$	**58.703**
(*c*)	$2\,Ag : NiBr_2$	**58.704**
(*d*)	$(NiBr_2 - Ni) : Ni$	**58.709**
[(*e*)]	$2\,AgBr : Ni$	**58.706**
[(*f*)]	$2\,Ag : Ni$	**58.707**
		59.706

If any assurance is needed that this average indicates very nearly the true atomic weight of nickel, the assurance may be found in the review of older work which follows. This review has been postponed until the close of the paper, in order that the methods might be judged in the light of our own experience with the subject.

A Brief Criticism of Earlier Work.

The atomic weights of nickel and cobalt have each been the subject of a score of different researches since the problem was first attacked by Rothoff in 1818. These investigations have not only led to exceedingly discordant results, but have also given rise to several interesting and important controversies. As a chronological list is given in our former papers,* there is no need of repeating it here. For the purpose of

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of finding the exact amount of the sulphuric acid, but in any case it was so small as to produce only a negligible effect on the result. From some experiments of Mr. Baxter's it is safe to assume that this error could not have exceeded 0.005 per cent in the worst cases, and in the average it must be still much less.

* These Proceedings, XXXIII. 97, 115.

criticism one should rather classify the investigations according to the methods used in them.

The most direct method of determining the atomic weight of nickel is obviously the reduction of nickelous oxide, for in this way the ratio between nickel and oxygen, the usually accepted standard of atomic weights, is settled at once. Russell, Zimmermann, Mond Langer and Quincke, Schützenberger, and Krüss and Schmidt * used this method with varying degrees of success. Of these five investigations the third was hastily undertaken only to show that nickel which has been vaporized as nickelcarbonyl is essentially similar to the ordinary material; the fourth included only two determinations made with oxide undoubtedly containing traces of sulphate, and the last was hopelessly faulty for reasons already discussed. Hence as exact criteria we may reject these three at once, and turn back to the much more carefully executed work of Russell and Zimmermann.

Russell showed that when the higher oxides of nickel and cobalt are ignited in an inert atmosphere, oxygen is driven off and the monoxide remains. His materials were contained in a Rose crucible of platinum; and after igniting the oxides in a stream of carbon dioxide, he reduced them in a stream of hydrogen. His nickelous oxide was very carefully freed from all extraneous matter except the insidious impurities derived from his glass vessels, against which no precautions were taken. A careful study of his work shows that this is the most serious cause of error likely to affect his final result, but that it was probably in part counteracted by the presence of occluded gases in the oxide; hence we have good reason to believe that this result is probably somewhat, but not much, too high.

Zimmermann followed essentially the same method as Russell. From ten exceedingly concordant analyses he deduced the value 58.694† for nickel, a value slightly lower than Russell's 58.743. His work also was carried out with great care, and the effort was made to avoid the occlusion of alkaline impurities by precipitating the final hydroxide of nickel

			Result.
*	1863	Russell, Jour. Chem. Soc., [2], I. 51,	Ni = 58.743
	1886	Zimmermann, Annalen (Liebig's), CCXXXII. 324,	Ni = 58.694
	1890	Mond, etc. Jour. Chem. Soc., LVII. 753,	Ni = 58.580
	1892	Schützenberger, Compt. Rend., CXIV. 1149,	Ni = 58.515
	1892	Krüss and Schmidt, Zeitschr. Anorg. Chem., II. 235,	Ni = 57.5 to 64. (!)

† Krüss and Alibegoff, who published Zimmermann's result, after his death, unwisely omitted to apply the correction to the vacuum standard. This omission has been supplied above.

with pure oxide of mercury, thus doing away with the use of an alkaline precipitant. This improvement also lessened the danger of Russell's other chief error, and at the same time introduced yet another with an opposite tendency, the inclusion of mercury; hence it is not surprising that his result should be somewhat the lower of the two. An unprejudiced critic cannot but consider Zimmermann's work as the best among the older researches, and it is pleasant to call attention to the fact that Zimmermann's result differs by only the fiftieth of one per cent from ours. The reason why this method gives a result more satisfactory in the case of nickel than in that of cobalt is probably because cobaltous oxide is so much more readily raised to the higher stage of oxidation. Both Russell's and Zimmermann's work may have been slightly vitiated by the presence of occluded hydrogen in their nickel; but it is impossible now to appraise the error involved, because the phenomenon is so irregular.

It is convenient to class together five more investigations which appeared between 1857 and 1871.* In the light of present knowledge concerning the possibilities of accurate quantitative work these contributions may be dismissed with few words. Marignac showed that Schneider's oxalate contained occluded impurities, and Schneider showed that Marignac's chloride could hardly have been both anhydrous and free from oxide. Our own experience entirely confirms both of these criticisms. Dumas's lack of ability to determine chlorine with accuracy throws out his analyses of the chloride at once, even if one is credulous enough to believe that the choride itself was pure. Sommaruga precipitated sulphuric acid from nickelous potassic sulphate as baric sulphate, a method now ostracised except for crude work. Lee's work was wonderfully accurate, considering the small quantities of materials which he used, but these quantities were so microscopic, and his compounds were so complex, that one could not have been expected to improve much upon his error of one per cent without a radical reformation of method.

Within this same period appeared another paper by Russell, elaborated as carefully as his previous one, but depending upon a less satisfactory process. The hydrogen evolved by the action of nickel upon hydrochloric acid was measured. Many uncertainties combine to make this

* (1857)	Schneider, Pogg. Annal., CI. 387, CVII. 616,	58.07
(1858)	Marignac, Arch. Sci. Nat., (nouv. sér.), I. 375,	58.90
(1860)	Dumas, Annalen (Liebig's), CXIII. 25,	59.02
(1866)	Sommaruga, Sitzber. Wien. Acad., LIV. [2], 50,	58.03
(1871)	Lee, Am J. Sci., [3], II. 44,	58.01

method of little value, so that the result (58.77 ?) does not carry with it much weight.

Three chemists in three different decades, Marignac, Baubigny, and Schützenberger,* have attempted to solve the question by the quantitative ignition of nickelous sulphate. The three investigations agreed fairly well upon an average result, 58.71,† Baubigny's being by far the most satisfactory. This method is one involving two errors which nearly counterbalance each other: — the sulphate has a tendency to retain water, while the oxide almost invariably retains sulphuric acid. For this reason, the method gives results which approximate closely to the truth.‡ Here again we have a support for the conclusion that the value in question cannot be far from 58.7.

All the published work upon the subject has now been referred to except some early work of Rothoff, Erdmann and Marchand, and Deville § (which deserves no more than a passing mention), and the more recent researches of Winkler. Krüss's misguided work has been sufficiently dissected by Winkler's able but unsparing criticism ‖ and in the experimental part of this paper. The only points not covered by Winkler, — the rose-colored flame test and the solubility of nickelous hydrate, are explained in the foregoing pages.

The work of Winkler is surprising in its variety and in the ingenuity of his methods, but unfortunately it is equally surprising in the wide range of one per cent between his several results. His earliest work,** depending upon the reduction of sodic aurochloride by nickel, giving the extremely high value 59.45, is obviously at fault. Winkler himself ignores it in his discussion,†† so that further criticism of it may well be omitted.

Winkler's two later investigations, carried out only a few years ago, gave results much lower and more satisfactory. In his first revision he weighed nickel, converted it into chloride, and determined the chlorine

			Greatest Difference from Mean.
* (1858)	Marignac, Arch. Sci. Nat., (nouv. sér.), I. 874,	Ni = 58.70	± 0.15
(1883)	Baubigny, Compt. Rend., XCVII. 951,	Ni = 58.78	± 0.002
(1892)	Schützenberger, Compt. Rend., CXIV. 1149,	Ni = 58.65	± 0.075

† Clarke, Recalculation, top of page 302.

‡ See "A Table of Atomic Weights," These Proceedings, XXXIII. 297, 298.

§ See Clarke, Recalculation, p. 291.

‖ Zeitschr. Anorg. Chem., IV. 10.

** 1867. Zeitschr. Anal. Chem., VI. 18. Ni = 59.45 (Clarke).

†† Zeitschr. Anorg. Chem , IV. 10, VIII. 1.

both gravimetrically and volumetrically.* He wisely regulated his operations in such a way as to avoid the use of alkalis; but in his ardor to escape this danger he encountered others as serious. It is highly unlikely that the electrolytic nickel, dried at only 50° while adhering to the dish, could have been free from impurities, as we have already shown in the experimental part of our paper. Indeed, he confessed in a later paper † that the electrolysis of cobalt at any rate is very far from being as accurate a process as it is sometimes supposed to be. The report of the acid reaction of the chlorides of these metals would have had more significance if the indicator had been named, for the salts destroy the magenta of phenol phthalein only because they remove the hydroxyl ions from the solution. Both chlorides are perfectly neutral to methyl orange. A loss of chlorine during the drying of either chloride would of course raise the observed atomic weight; and while in the case of nickel the loss was so small as not to have produced a visible cloudiness, no proof is offered that no loss took place. In the case of the cobalt "eine gewisse, aber so schwache Trübung, dass sie, wie man zu sagen pflegt, nicht 'blank' erschien" involved a loss of as much as one per cent of material, and it is well possible that a smaller but still important amount of basic salt may have escaped notice in the case of the nickel. Our own experience with the halides of both metals convinces us that it is quite impossible to obtain them pure and dry by evaporating to dryness in moist air. Turning now to the determination of the chlorine in the salts, we find other grave flaws. No account was taken of the solubility of argentic chloride in the gravimetric work, and several milligrams must have been washed away by the hot dilute nitric acid used as a washing fluid. One is surprised, too, to find that the antiquated process of burning the filter was adopted, instead of Gooch's admirable substitute. In the volumetric work again the solubility of argentic chloride was overlooked, although it produces a most injurious effect on the method of Volhard.‡ It is indeed surprising to see so eminent a chemist using volumetric methods at all in this way, for every one knows the difficulty of obtaining results of a very high grade of accuracy by their aid. In this laboratory the burette is only called into use when at least ninety-nine per cent of the material has been weighed out, and then only a few cubic centimeters of a very dilute solution are added to

* Zeitschr. Anorg. Chem., IV. 10, 1893.
† Zeitschr. Anorg. Chem., VIII. 4.
‡ These Proceedings, XXVI. 34, and XXIX. 67.

complete the quota. This is quite a different story. It is evident that nearly all the errors mentioned tend to make Winkler's result too high.

Some singular oversights appear also in the calculation of the results. For example, in one place Winkler compares 0.1662 gram of nickel with 0.6079206 gram of silver. The small amount of nickel was deposited in a large platinum dish, and its weight could certainly not have been determined more accurately than within 0.1 milligram, hence at least three decimal places of the recorded weight of silver were superfluous, even if the volumetric solution could have been prepared with an error of only one part in six millions. It is perhaps well to mention also that his final results, varying in the case of cobalt from 59.5996 to 59.7480 (if $O = 15.96$) are given as far as four decimal places.

While a review of this work is necessary in order to explain why the results should be too high, perhaps one should not be severe in one's criticism of it, for Professor Winkler himself rejects it, as well as some later work on cobalt,* in his most recent contribution upon the subject.† In this new paper he pins his faith to another series of determinations made in 1894, with a very ingenious method adopted after sundry fruitless attempts in other directions. It behooves us then to consider this later work with great care.‡

Evidently many of the errors which render the older investigation untrustworthy were eliminated from that of the subsequent year. The nickel was separated from the platinum dish and afterwards ignited in an atmosphere of hydrogen, and the solubility of argentic chloride does not enter into the question. On the other hand, the unfortunate use of volumetric operations and the misuse of figures remained, while to these were added other dangers not present in the older work. The ingenious procedure was as follows: pure nickel was acted upon by pure iodine, and the excess of iodine was determined by sodic thiosulphate. Many textbooks upon volumetric analysis name the process of iodometry as one of the most accurate of titrimetric methods simply because the end point is an extremely sharp one. In reality, the lack of permanence of the necessary solutions render it distinctly unsuitable for very accurate work even under the best conditions. When the iodine must

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* Zeitschr. Anorg. Chem., IV. 462.

† Zeitschr. Anorg. Chem., XVII. 236.

‡ 1894 (1895), Winkler, Zeitschr. Anorg. Chem., VIII. 1, 291; $Ni = 58.85$. It must be borne in mind in referring to Winkler's papers that he uses the old standard $O = 15.96$. His values have all been translated into the more convenient notation ($O = 16.000$) in this paper.

remain in solution for twenty-four hours after weighing and before titration, and when this circumstance is complicated by the presence of a metal capable of acting to a slight extent even upon pure water in the presence of air, one can hardly contend that the conditions are the best. The chance of side reactions seems to be too great to admit of infallibility in the results. One is surprised, indeed, that Winkler's results approach as near to those of Zimmermann as they do, and this close approach is evidence of great accuracy of manipulation on Winkler's part. In short, viewed from the standpoint of ordinary analytical experience, Winkler's last work is admirable, while from the standpoint of atomic weight research it is inadmissible. In justice to Professor Winkler it is only fair to add that he realizes this fact himself.* One need not dwell upon possible inaccuracies, however; for Winkler himself has furnished us with data for computing the error of his method. In a short paper he uses the same method for determining the atomic weight of iron, and finds for this quantity the value 56.174, if $O = 16.000$.† Now according to the fairly consistent work of Berzelius, Erdmann and Marchand, Svanberg and Norlin, and Maumené, the atomic weight of iron cannot be far from 56.02; and there is no contradictory evidence of serious value.‡ Winkler's method then gave him a result 0.275 per cent § too high in the case of iron, and it is fair to conclude that the error could not have been far different in the case of nickel. Making the corresponding subtraction, Winkler's corrected result approaches astoundingly near to those obtained by Zimmermann and by us.‖

Winkler's corrected value	58.69
Zimmermann's value	58.694
Richards and Cushman's value	58.706
Average	58.70

Owing to a slight uncertainty in the atomic weight of iron, as well as to the possibility that iron may behave somewhat differently from nickel

* Zeitschr. Anorg. Chem., XVII. 239.

† Zeitschr. Anorg. Chem., VIII. 291.

‡ Clarke's recalculation, p. 289. The atomic weight of iron is now being further studied in this Laboratory.

§ It is possible that a small part of this error is due to the omission of the reduction to the vacuum standard, which would affect the final value by about 0.01 per cent. This correction may have been applied, but there is no evidence of such application.

‖ Mr. Baxter first called our attention to this remarkable unanimity.

in iodine solutions, this comparison is less significant than it seems to be; but certainly it does not militate *against* our value for the atomic weight of nickel. It is of interest to note that Clarke's mathematical method of selecting from among the older values led to the number 58.687.

Professor Winkler's sixth and last paper upon this subject appeared only last summer, after the work described in this paper had been completed.* In it he kindly points out several possible flaws and omissions in our earlier paper. This criticism will be discussed at length in the next paper on cobalt.

CAMBRIDGE, MASS., October 22, 1898.

* Zeitschr. Anorg. Chem., XVII. 236.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF COBALT.

SECOND PAPER. — THE DETERMINATION OF THE COBALT IN COBALTOUS BROMIDE.

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Presented October 12, 1898. Received December 29, 1898

IN a recent paper upon the atomic weight of cobalt,* we began the analysis of cobaltous bromide by the determination of its bromine, with results which seemed to show that the atomic weight of cobalt is very nearly 58.99 (O = 16). Although very great care was taken in purifying the cobaltous bromide used in this work, it was never certain that during the sublimation of the bromide in the porcelain tubes small amounts of impurity had not crept in. The situation here was exactly the same as in the research upon nickel, carried on at the same time in this Laboratory,† and here also the simplest and most convincing way of settling the question was to determine directly the amount of cobalt present in the salt, thus obtaining its total percentage composition.

Of the three methods of procedure which presented themselves, — precipitation, electrolysis, and reduction of the bromide, — reduction by hydrogen was chosen as being the least complicated and most certain. The slight hope offered in the nickel research that electrolysis might be used for the determination of the metal was here lacking on account of the greater difficulty in obtaining a satisfactory electrolytic deposit.

A conceivable objection to the use of the reduction of an *oxide* as an accurate quantitative method is the possibility that this reaction may not be capable of absolutely complete fulfilment. It is well known, for example, that one is rarely able to reoxidize wholly a metal once reduced,

* These Proceedings, XXXIII. 115.

† The preceding paper describes this work. This Volume, p. 327.

even if the material is finely divided. In the case of the oxide there is no means of deciding whether or not the last traces of oxygen have been removed, while in the case of the *bromide* a residue of halogen is easily detected. The complete reduction of nickelous bromide described in the preceding paper shows that some such operations are in fact possible. It is easy to see how the increase in volume involved in oxidation might cause a part of the metal to be permanently protected by the growing coat of oxide; on the other hand, an oxide or salt which is being reduced leaves only its skeleton behind, the innermost meshes of which may be penetrated by the reducing agent.

Cobaltous bromide when heated in a current of dry hydrogen begins to be reduced at a temperature of about 350°. At higher temperatures the reduction goes on more rapidly, but is then accompanied by partial sublimation of the bromide. Schützenberger's* observations on the sublimation of nickelous chloride were similar to these, but he seemed to think that some strange compound must have been the medium of the change, instead of realizing that in the presence of hydrochloric acid a trace of the vapor of the metallic salt might easily exist even in an atmosphere of hydrogen.

If the hydrogen is *moist*, however, the action begins at a lower temperature, about 250°; but even under these conditions sublimation can be completely avoided only with the greatest difficulty. The reduction of *nickelous* bromide offered fewer difficulties; this process could be effected in a current of dry hydrogen, and without danger of sublimation of a trace of the material. The fact that moist hydrogen is more efficient than the dry gas is easily explained by the hypothesis that the oxide is formed as the first step in the reaction.

Purification of Materials.

Preparation of Cobaltous Bromide. — The cobaltous bromide used in this work was prepared by methods similar to those used in our previous investigation, and for details the previous paper should be consulted. Pure metallic cobalt was heated in a current of pure bromine and hydrobromic acid, and the sublimed bromide was preserved in weighing bottles contained in desiccators until used for analysis. Samples I. and II. were essentially the same as in the earlier investigation, even greater pains having been taken, however, in the purification of the reagents and water used in their preparation. Sample III. likewise was purified by

* Compt. Rend., CXIII. 177.

essentially the same method as before, but was then further treated by six additional recrystallizations as the purpureo-chloride, with the help of very pure redistilled ammonia and hydrochloric acid. The oxides obtained from these preparations were finally reduced by means of pure hydrogen, instead of by ammonia as before.

Preparation of Bromine. — Here also the process of purification did not differ from that previously employed. The purity of the bromine is sufficiently proven by two analyses in which a known weight of silver was precipitated by a slight excess of ammonic bromide made from the halogen.

Ag in Vacuum. grams.	AgBr in Vacuum. grams.		AgBr : Ag
2.91386	5.07226		57.447
2.97097	5.17170		57.447
		Average	57.447
		Stas found	57.445

The balance and weights used in this work were the same as those described in our previous paper. The weights were carefully restandardized, the values differing from those previously found by only a few hundredths of a milligram. Since the balance was wholly free from iron, no inaccuracies could have arisen from magnetic attraction, either in this work or in that upon nickel.

Owing to the fact that the specific gravity of cobalt is almost identical with that of brass, no correction was required to reduce the weight of the cobalt to a vacuum standard.

The correction of +.00010 gram per gram of cobaltous bromide was applied in each case to the weighings of that material. All weighings were made by substitution, as usual.

We are indebted to the Cyrus M. Warren Fund for Chemical Research in Harvard University for some of our more expensive pieces of apparatus.

Method of Analysis.

By means of the glass apparatus described in our earlier paper, cobaltous bromide, contained in a platinum boat, was dried in a current of pure dry nitrogen and hydrobromic acid gas in a hard glass tube heated to about 400°; and after the tube had been thoroughly swept out with nitrogen and then by dry air, the boat was transferred to a weighing bottle in this safe atmosphere. The bottle was then weighed, and the

boat carefully placed in the reduction tube, where it was heated in a current of moist hydrogen until the fumes of hydrobromic acid ceased to come off. The tube was then swept out with dry hydrogen, and when cool the boat was quickly replaced in the weighing bottle containing dry air, and was thus weighed after a suitable delay. In most analyses this process was repeated until the weight of the cobalt ceased to change. Cobalt reduced from the bromide is less constant in weight than nickel, gaining several tenths of a milligram in weight in twenty-four hours.

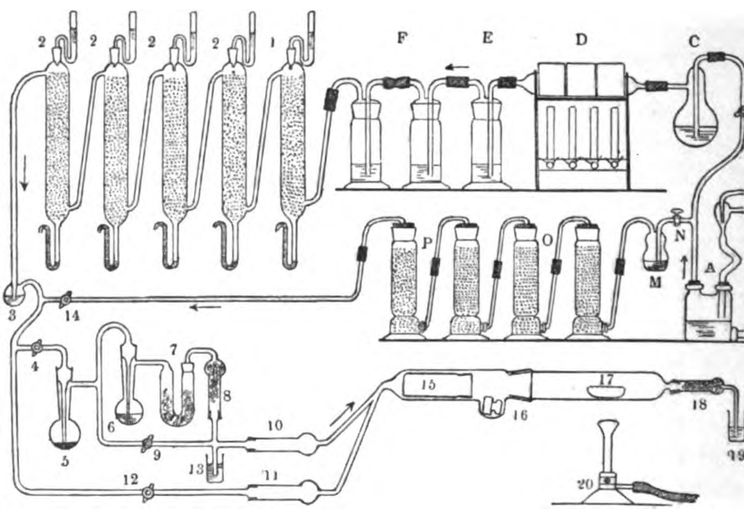

Fig. 1. Apparatus for igniting Cobaltous Bromide in any desired Mixture of Gases.

The use of rubber was confined to the first part of this train, where it could do no harm (A B C D E F and A M N O P).

For this reason the metal was always allowed to become thoroughly cool in the atmosphere of hydrogen, and the weighing bottle was allowed to come to perfect equilibrium with the atmospheric conditions inside a desiccator at the room temperature before receiving the boat. After half an hour *nickel* treated in the same way had been found to come to constant weight, and in half an hour the opportunity for oxidation of cobalt is so slight as to be negligible; hence this interval was the one which always elapsed between the bottling and the weighing of the cobalt. In one analysis, to see if exposure to the air affected the weight of the cobalt, the boat was bottled in dry nitrogen in the bottling apparatus, after

being heated to constant weight in the usual way. Upon correcting the weight of the bottle for the difference in weight of nitrogen and air, the weights obtained by both methods agreed perfectly.

The resulting cobalt was in the form of a gray metallic sponge, which showed no traces of oxidation upon standing in air. Since previous work by other experimenters* is not unanimous as to the occlusion of hydrogen by cobalt under these circumstances, it seemed desirable to us to obtain more evidence on this point. Accordingly, in several analyses the boat containing the cobalt was placed in a hard glass tube sealed at one end. After the air had been exhausted by means of a Sprengel pump, the tube was heated to about 500°, the highest temperature used in the reduction. In no case was a measurable quantity of gas evolved, and the cobalt did not lose in weight; hence it would appear that cobalt prepared from the bromide does not possess the property of occluding important amounts of hydrogen when heated in the gas.

To avoid any possibility of error, two and a half grams of cobalt, freshly reduced from the bromide aud allowed to cool in hydrogen, were subjected to quantitative combustion in the manuer already described in the paper upon nickel. Only five tenths of a milligram of water were formed; and even the repeated reduction and combustion of the residual oxide yielded only a milligram. Evidently the amount of hydrogen occluded was very small. On the other hand, cobalt reduced originally from the oxide, when treated in the same way, was found to contain about fifteen times its volume of hydrogen and when allowed to remain in hydrogen several hours, it was found to have absorbed amounts comparable to those found by Neumann and Streintz.† A fuller statement of the experiments will be reserved for a future paper upon the nature and causes of these singular irregularities; for the present, it is sufficient to have shown that cobalt, like nickel, reduced from the bromide, does not retain enough hydrogen to vitiate the results recorded below.

It is perhaps worth while to state also that the empty platinum boat was tested as to its power of absorbing weighable amounts of hydrogen. After ignition and cooling in the gas, and bottling in dry air as usual, it was found to have gained 0.02 milligram when compared with its weight after ignition in air. Evidently the occlusion of hydrogen, if measurable at all, is balanced by adsorption of air; hence for our purpose it may be neglected.

* Neumann and Streintz, Monatshefte für Chem., XII. 642; Berichte d. d. ch. Gesell., XXV., 187R; Hempel and Thiele, Zeitschr. Anorg. Chem., XI. 93.

† *Loc. cit.*

A slight sublimation of the cobaltous bromide took place during the reduction in almost every case. The amount of this sublimed material was determined by washing out the tube with a few cubic centimeters of nitric acid, and evaporating this liquid to dryness. After the solution of the residue in water and the addition of an excess of ammonia, a very dilute standard solution of potassic permanganate was run in until a pink color appeared. This method of Winkler's is applicable only when extremely small amounts of cobalt are present, because the brown color of the cobaltic salt interferes seriously with the end point in the presence of large amounts of cobalt. The weight of the cobaltous bromide thus sublimed never amounted to more than three tenths of a milligram, and seldom exceeded one tenth of a milligram.

The platinum boat used in the earlier work served to contain the bromide in these experiments also. Although the metallic cobalt alloyed itself with the surface of the boat to a slight extent, we were able to remove completely the alloy by treating the inside of the boat with aqua regia. After this treatment and scrubbing with round sand, the boat showed no trace of darkening upon ignition. Evidently, then, the cobalt had been completely removed. Of course a gradual loss of weight took place, owing to solution of small amounts of platinum, but this loss amounted to only half a gram in the course of the work.

In the first two determinations the hydrogen was generated from hydrochloric acid by means of pure zinc. It was purified by passing through bulbs containing silver nitrate, potash, silver nitrate again, then through a hard glass tube heated to redness. From this point the gas came in contact only with glass, being conducted through three towers containing glass beads moistened with silver nitrate, then by means of T-tubes, either directly in a moist state, or through a long drying tube containing stick potash, into the reduction tube. The reduction tube was connected with the rest of the apparatus by means of a ground glass joint.

A small amount of white sublimate, which appeared beyond the boat during each of the preliminary ignitions, proved to be ammonic bromide. The source of the ammonia was not at first apparent, as it was hard to believe that the cobaltous bromide could retain ammonic bromide at a temperature between 400° and 500°. Upon examination of the silver nitrate columns it was found that reduction had taken place there, metallic silver being precipitated upon the beads.* Of course the reduction of

* The fact that silver nitrate is reduced by molecular hydrogen has already been noted by other experimenters: Russell, Jour. Chem. Soc., [2], XII. 3, (1874); Pellet, Compt. Rend., LXXVIII. 1132.

the silver alone could do no harm; but unfortunately it was attended by a reduction of the nitric acid also. This was proved by passing the resulting gas through a hot tube, when traces of ammonia were formed, capable of easy detection by Nessler's reagent. We had come face to face with one of those frequent cases where an attempt at purification had introduced a flaw as serious as the one it eliminated. The very common use of argentic nitrate as a means of purifying hydrogen is obviously a pernicious one, if accurate results are desired.

The hydrogen apparatus was then entirely remodelled. Owing to the fact that the amount of hydrogen required for the completion of a reduction was very much larger than the amount actually necessary to combine with the bromine,* a gasometer was constructed which should collect the hydrogen after it had passed through the tube and deliver it repeatedly to the apparatus, after removal of the hydrobromic acid. The hydrogen was generated by a primary battery consisting of zinc amalgam, hydrochloric acid, and platinized platinum. The gas delivered by this apparatus is pure, except for the presence of a little hydrochloric acid, which can be removed easily by means of potash. The following cut shows the apparatus in its improved form.

The bottle *B* is filled with pure hydrogen generated by the battery *C*. From the bottle *A* water is siphoned into *B*, forcing the hydrogen by way of the stopcock *e* through the column *D*, filled with beads moistened with aqueous cupric sulphate to remove sulphur compounds taken from the rubber; through the columns *E* and *F* which contain dilute sodic hydrate, then either directly through *g* or through a potash tube *G* into the reduction tube *H*. After being freed from hydrobromic acid in the bottle *K* containing potash, the gas is conducted through the open stopcock *b* into *A*. When *B* is full of water the process can be repeated by interchanging *A* and *B*, and opening the stopcocks *c* and *d* after closing *b* and *e*. The generator *C* served to keep the pressure always outward. The current of gas could be regulated by a pinchcock *a* on the rubber siphon tube. This apparatus proved entirely satisfactory, and was not altered during the investigation.

As in the case of nickel, it was found impossible by reduction alone to remove the last traces of bromine from the spongy cobalt. Even long continued heating to a temperature much above the subliming point of cobaltous bromide failed to give complete reduction, the solutions of the reduced cobalt giving decided tests for bromine. In the first

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* See the preceding paper, p. 333.

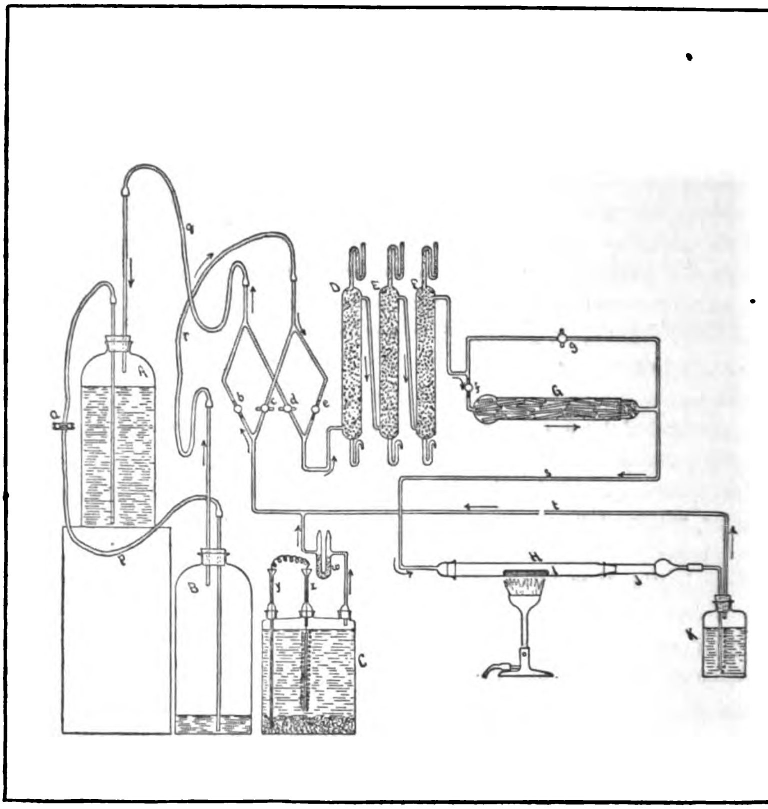

FIG. 2. APPARATUS FOR REDUCING THE BROMIDE.

analysis this bromine was precipitated with an excess of silver nitrate and weighed. In analyses 2, 3, and 4 the cobalt was leached with pure water, and after filtration the bromine was determined in the filtrate. The solutions of the cobalt in dilute nitric acid proved almost entirely free from bromine, that obtained from analysis 4 being entirely so. The silver bromide from these solutions was combined with that obtained from the aqueous extracts and weighed. As it was hard to believe that cobaltous bromide could be enclosed by the reduced cobalt in such a way as to remain unreduced and yet to go completely into solution with apparent ease, it was obvious that some foreign bromide must be present. Accordingly the filtrate from one of the precipitates of silver bromide

was treated with an excess of hydrobromic acid in order to remove the silver, and the refiltered solution was evaporated to dryness. Upon a careful qualitative analysis tests were obtained for nothing but sodium and traces of cobalt. The sodium evidently came from the porcelain tube used in the sublimation, and we were dealing with an impurity precisely similar in source and nature to that described in the case of nickelous bromide. As the two investigations progressed side by side, the discovery was almost simultaneous in the two cases. We have already said that this outcome was not an unexpected one.

Since it would be impossible to calculate the weight of the soluble bromides from the weight of the silver bromide without a quantitative analysis of the two bases present, the effort was made to evaporate the aqueous extract from the reduced cobalt and to weigh the dried residue directly. In the work upon nickel this method was necessarily rejected because the spongy nickel was oxidized and went into solution as nickelous hydrate which could not be removed by filtration. Our spongy cobalt oxidized much more rapidly than the nickel upon treatment with water; but the decantate, upon filtration and evaporation in the air, deposited most of its cobalt as cobaltic hydroxide. The presence of salts of the alkalis greatly increases this oxidation, cobalt which has once been leached being oxidized but little. Heat also increases the oxidation, and so probably does the galvanic action with the platinum dishes which were used wherever possible through the whole course of this investigation.

In view of the colloidal solubility of nickelous hydrate in water, it is probable that cobaltous hydrate possesses the same property. When cobalt is treated with water in the presence of air, the metal oxidizes and goes into solution as *cobaltous* hydrate; this is then further oxidized by exposure of the solution to the air and thrown out of solution as *cobaltic* hydrate, which can be filtered off. Since the dissolved cobalt is almost completely removed by this process, it is obviously legitimate to weigh the residue obtained by evaporating the aqueous extract of the reduced cobalt, and thus to obtain directly the amount of impurity present in the metal. This difference of procedure in the two cases is an interesting example of the way in which subordinate side reactions may influence two researches otherwise unusually analogous.

In the next four analyses (5 to 8) the cobalt was leached with the purest hot water in a platinum dish and the solution, after filtration, was evaporated to dryness. The residue was taken up with water, filtered from the deposited cobaltic hydroxide into a weighed platinum crucible, again evaporated, heated to 130°, and weighed. That these residues contained

cobalt was undoubtedly true from the fact that they were colored a pale blue both after evaporation and after heating. During the heating however a slight blackening took place which was due to the oxidation of traces of unoxidized cobaltous hydrate. In order to make sure that all unreduced bromides had been removed from the cobalt by the process of leaching, in each analysis the metal was dissolved by cold very weak nitric acid* and treated with silver nitrate. As not even the faintest cloudiness was ever again visible in these solutions, it was assumed that the soluble matter had been completely removed.

In analysis 5 the bromine in the residue was determined and the result found to be considerably too low to correspond with the weight of the residue, if calculated as sodium bromide. In order to discover the cause of this discrepancy an elaborate series of experiments was carried out at the expense of much time and labor. To describe these experiments in full would result only in confusing the mind of the reader. It is sufficient to say that pure spongy cobalt was treated with varying amounts of pure sodium bromide in solution, the conditions being regulated so as to be as nearly as possible like those in the analyses. The following conclusions drawn from these experiments are of great importance.

In the first place, no bromine is lost by the residues either during evaporation or in heating to 130°. The cobalt in the residues may be present in three forms, as cobaltous hydrate which has escaped oxidation, as cobaltic hydrate, and as unreduced cobaltous bromide,† each in exceedingly small amounts. The doubt as to the quantity of each present makes it impossible to apply the correction for dissolved cobalt with any degree of accuracy and in the table of results no attempt has been made to do so. In the later analyses this cause of uncertainty was removed.‡ This correction within a correction is however an infinitesimal of the second order; neglecting it can produce no serious effect upon the accuracy of the final result.§ In this respect the research upon cobalt differs from that upon nickel, where the amount of hydroxide in the residue was relatively great, owing to the fact that it had not been chiefly eliminated by oxidation during the evaporation.

* In a platinum dish this solution takes place with great ease, and with no danger of a loss of bromine. The galvanic action is a great assistance.

† Cobaltous bromide could only have found its way into this residue by having been protected from reduction by enclosure in crystals of sodic bromide. It must have been exceedingly small in amount, if present at all.

‡ Compare page 368.

§ This extra cobalt may partly explain why the sum of the total analysis slightly exceeds 100.000 per cent. See page 365.

The possibility of the presence of some other acid than hydrobromic acid in the residues led us to make tests in this direction. Silicic acid was of course the first one to suggest itself. Early in the work one test had been made by subliming about two grams of pure cobaltous bromide from a platinum boat in a current of hydrobromic acid gas. After the sublimation of the bromide the boat was perfectly bright, and gave not the slightest evidence of the presence of any silica. One of the residues was now treated with pure strong hydrochloric acid, heated to 130°, again treated with hydrochloric acid, and filtered. The amount of silica found, three one-hundredths of a milligram, is a negligible quantity. Although the purity of the phosphoric anhydride used for drying our gases had been proven by passing air through a tube filled with the pentoxide into aqua regia, which upon evaporation gave no precipitate with ammonic molybdate, nevertheless one of the soluble residues from the reduced cobalt was tested with the same reagent with a negative result.

Upon examining one of the earlier residues for sulphuric acid, however, a slight precipitate of baric sulphate was formed. The source of this sulphuric acid was hard to discover, but finally it was found that the strong sulphuric acid in some of the drying columns had become discolored in places by organic matter. This must have led to a slight decomposition of the acid and formation of sulphur dioxide, which was subsequently oxidized to sulphuric acid by the bromine. The amount of sulphuric acid present in the bromide was very small, 3.88 grams of cobaltous bromide giving only 0.00036 gram of baric sulphate in one case. As in the instance of nickel, however, this cause of error was wholly eliminated in the later experiments, and no trace of sulphuric acid could be detected in the material used in the last series.

The conclusions to be drawn from these experiments seem to be: —

First, that our cobaltous bromide was almost if not completely reduced.

Secondly, that the impurities, which consist of alkaline bromides (with, in some cases, a minute trace of sulphates), can be completely removed by leaching the cobalt.

Thirdly, that the residue obtained by evaporating the water extract of the cobalt after reduction represents within an exceedingly small amount the weight of the impurities.

In the fourth series, during which the truth of this third conclusion was not realized, and a method similar to that used in the nickel research was adopted, the weight of the residue had to be calculated. The basis of calculation was the knowledge obtained from analysis 5, Series V. Unfortunately this is the only analysis of material similar to that used in

Series IV., where both the weight of the residue and the silver bromide obtained from it were determined. Since, however, the use of this analysis causes the average of Series IV. to approach within one part in thirty thousand of the average of Series V. and VI., we may safely assume that the rather meagre data represent with great exactness the real weight of the impurity contained in this Sample I. of cobaltous bromide. In Series V. and VI. the residues were weighed directly, so that this factor was not needed. Below are given the results of the first two series of analyses.

THE ATOMIC WEIGHT OF COBALT.

$O = 16$; $Br = 79.955$.

Fourth Series (Preliminary). $CoBr_2 : Co$.

No. of Anal.	Sample of $CoBr_2$.	Observed Weight of Cobaltous Bromide in Vacuum.	Observed Weight of Cobalt in Vacuum.	Weight of AgBr found from Residue.	Weight of Residue calculated from AgBr.*	Atomic Weight of Cobalt.
		grams.	grams.	grams.	grams.	
1	I.	5.59216	1.50873	0.00309	0.00193	59.007
2	I.	4.61944	1.24807	0.00681	0.00426	58.996
3	I.	3.75291	1.01713	0.01267	0.00793	58.989
4	I.	3.00645	0.81409	0.00815	0.00510	59.007
					Average . .	59.000

Fifth Series. $CoBr_2 : Co$.

No. of Anal.	Sample of $CoBr_2$.	Observed Weight of Cobaltous Bromide in Vacuum.	Observed Weight of Cobalt in Vacuum.	Weight of Residue.	Corrected Weight of Cobaltous Bromide.	Corrected Weight of Cobalt.	Atomic Weight of Cobalt.
		grams.	grams.	grams.	grams.	grams.	
5	I.	5.32955	1.44189	0.00761*	5.32194	1.43428	58.996
6	I.	7.51430	2.02965	0.00644	7.50786	2.02321	58.989
7	II.	2.32910	0.62957	0.00280	2.32630	0.62677	58.973
8	II.	7.45336	2.01378	0.00642	7.44694	2.00736	59.011
						Average . .	58.992

* From the residue in Series V., analysis 5, was obtained 0.01216 gram of

It seemed highly important to us at this point to prepare cobaltous bromide which should be free from every impurity. In the first place the drying apparatus was slightly modified, no strong sulphuric acid being used except in drying the air necessary for sweeping the nitrogen out of the weighing bottle. Dilute sulphuric acid was substituted in every case, and two columns of stick potash followed by one of phosphoric anhydride were inserted beyond this dilute acid. As the porcelain tubes had evidently been the source of the alkaline impurities found, a platinum lining, made by bending a large piece of platinum foil into the form of a cylinder, was provided for the outside porcelain tube.* The smaller porcelain tube was not used at all, the sublimed material being removed by taking out the foil and unfolding it. Cobalt from Sample III. was then sublimed in the remodelled apparatus from a platinum boat. The material obtained in this way gave results for the atomic weight altogether too high, a circumstance due to large quantities of platinum actually found in the sublimed bromide. Even here a small amount of alkaline impurity existed, having crept in through the crack in the platinum foil. Hence, no more work was done with this material; but renewed precautions were taken to prepare by the older method cobaltous bromide which should contain the smallest possible number and quantity of impurities.

Four analyses were made with this new material, which proved in spite of all our care to contain as much soluble matter as before. The water extracts from these analyses were evaporated in a flat platinum dish, which exposed a large surface of the solution to the air. This served to oxidize completely the dissolved cobaltous hydrate, for the residues did not become gray when heated, and upon the addition of water gave perfectly clear solutions. These residues were faintly blue, the color being due doubtless to a trace of unreduced cobaltous bromide. For some undiscovered reason, the amount of silver bromide obtained from the residues was still too small to correspond to the weight of the residue, if calculated as sodic bromide.

Tests were repeated for sulphuric, phosphoric, and silicic acids with the greatest possible care, but still with negative results. In one analysis the cobalt was determined in the residue and found to be only 0.00013 gram. It is possible, however, that these few tenths of a milligram dis-

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argentic bromide. Hence 0.0010 gram of argentic bromide corresponds to 0.000626 gram of residue. This factor is used in calculating the results in Series I.

* Compare the preceding paper on Nickel, page 331.

Weight of Residue.	Weight of AgBr obtained from Residue.	NaBr in Residue, calculated from AgBr.	Unidentified.
grams.	grams.	grams.	grams.
.00306	.00439	.00240	.00066
.00643	.00978	.00536	.00107

crepancy are due to the presence of all or at least several of the above mentioned acids combined with sodium, each in quantity too minute for detection; and for the present this will have to rest as the explanation.

Sixth Series. $CoBr_2 : Co$.

No. of Anal.	Sample of $CoBr_2$.	Observed Weight of Cobaltous Bromide in Vacuum.	Observed Weight of Cobalt in Vacuum.	Weight of Residue.	Corrected Weight of Cobaltous Bromide.	Corrected Weight of Cobalt.	Atomic Weight of Cobalt.
		grams.	grams.	grams.	grams.	grams.	
9	III.	5.11197	1.38027	0.00306	5.10891	1.37721	59.016
10	III.	6.41822	1.73333	0.00483	6.41339	1.72850	58.999
11	III.	6.60707	1.78778	0.00902	6.59805	1.77876	59.021
12	III.	3.03497	0.82249	0.00643	3.02854	0.81606	58.982
						Average . .	59.004

Average of Series V. and VI. . . Co = 58.998.

This final average differs from that published before by only about one part in ten thousand; but in comparing the two one must remember that the material used last year must have been contaminated by the same impurities which have been discussed in this paper. If the impurity contained as much bromine as cobaltous bromide contains, it would have had no effect upon last year's results. In the case of *nickel*, where the impurity consisted wholly of sodic bromide, the effect of correcting the observed results in the paper of 1897 was to raise the atomic weight of nickel from 58.688 to 58.703. The impurity from our *cobaltous* bromide, on the other hand, contained unknown substances in quantities so small as to elude detection, but large enough to change the sign of the corresponding correction. Thus 22.63 grams of cobaltous bromide in Series V. (the series in which the materials most nearly

resembled those used in Series II. and III. of last year's work) were found to contain 0.02327 gram of impurity. If, as we may reasonably suppose, all the residues obtained from this sample of material resembled that found in analysis 5, Series V., this residue would have yielded 0.0372 gram of argentic bromide. We may now correct last year's results by subtracting from the several weights of cobaltous bromide proportional weights of impurity, and also subtracting from the several weights of argentic bromide amounts of this substance corresponding to the impurity. Making this correction, the atomic weight of cobalt would be *lowered* 0.008, the averages of Series II. and III. becoming 58.987 and 58.979. Our uncertainty regarding the nature and amount of the impurity thus involves an uncertainty of about one part in six thousand in last year's results. In the light of all the circumstances, it is perhaps safest not to attempt any correction of these values, but to accept them uncorrected as subject to this possible error. The results are accordingly given below in an uncorrected form.

The data just discussed obviously afford a basis for recording the total percentage composition of the cobaltous bromide analyzed.

COMPLETE ANALYSIS OF COBALTOUS BROMIDE.

Based upon Series II., III., and V.

			Per cent.
Cobalt (Series V.)		. . . . =	26.923
Total Bromine	(II.) 73.050% (III.) 73.053% Aver. 73.051% =	Bromine combined with Cobalt =	72.981
		Bromine actually found in impurity =	.070
Total impurity . .	= 0.103% =	Remainder of impurity (chiefly Sodium) =	.033
		Total . . . . . . =	100.007

Series VI., perhaps the best of all, is not included in this table because the material used in it was not quite identical with that used in the three other series. Obviously it is possible to calculate two more ratios involving the atomic weight of cobalt, in which the values for the *bromine* in the bromide are compared with the *cobalt* found in it. Into this calculation the weight of the bromide itself enters simply as a constant, and an indifferent impurity (such as water) would be eliminated from the

result. The table below includes all of the five possible ratios obtainable from our work, series I. and IV. being rejected because they were merely preliminary: —

2 AgBr	:	$CoBr_2$	(Series II.)	58.995
2 Ag	:	$CoBr_2$	(Series III.)	58.987
$CoBr_2$	:	Co	(Series V. and VI.)	58.998
2 AgBr	:	Co	(Series II. and V.)	58.994
2 Ag	:	Co	(Series III. and V.)	58.992
			Average	58.993

This table, although giving an interesting statement of the possible combinations, does not yield a fair average, — for Series V. is introduced three times, Series II. and III. each twice, while Series VI., which is at least as accurate as the others, appears only once. A fairer method would probably be to avoid all hypotheses and combinations, and assign to each of the four series equal weight, as follows: —

Series II. (uncorrected)	Co	=	58.995
Series III. (uncorrected)	Co	=	58.987
Series V. (corrected)	Co	=	58.992
Series VI. (corrected)	Co	=	59.004
Final Average . . .			58.995

Obviously it makes but little difference which method we adopt: the averages are essentially identical. The highest individual experimental result among all these determinations was 59.021, and the lowest 58.955, the average variation from the mean 58.995 being 0.012. Because these results are less concordant than one could wish, and the conclusion is somewhat less positive than that reached in the case of nickel, the atomic weight of cobalt is being further studied by radically different methods in this Laboratory.

In a recent article,* Professor Winkler calls attention to some possible errors, in the work upon both nickel and cobalt published last year. That the disagreement between his results and ours is due to the methods employed by him in his work upon these two elements has been sufficiently shown in the preceding paper upon the atomic weight of nickel. In addition, however, his several suggestions concerning our own work should obviously be reviewed and discussed in detail.

His specific criticisms are four in number. First, he suggests that the

* Zeitschr. Anorg. Chem., XVII. 236.

porcelain tubes might have been attacked during the sublimation of the bromides, with the introduction of foreign bromides into the nickelous and cobaltous bromides. He goes on to state that the bromides were dried in an acid atmosphere, and probably retained hydrobromic acid after this gas had been displaced by air. His third criticism is that the nickelous bromide in the earlier analyses contained nickelous oxide which had to be determined and subtracted; and his final objection applies to the use of the Gooch crucible.

Answers to the greater part of his criticisms can be found in the very articles which he criticises. In one case only can his view be substantiated; — the porcelain tubes are really attacked. That this flaw was a possibility we realized at the time; but we also realized the smallness of the error introduced by even a comparatively large amount of such impurity. This matter has been already discussed in detail, both in this paper and in the paper upon the atomic weight of nickel.

There are two possible ways in which hydrobromic acid could have been retained: — by adsorption and by inclusion. At the high temperatures employed the adsorption must have been very slight, and the long process of washing with an indifferent gas was favorable to the elimination of any tendency in that direction. While the inclusion of *liquids* is a very serious possible cause of error, that of *gases* is usually negligible because of the small mass involved. For this reason crystallization from solutions is far less satisfactory than sublimation as a means of purification.

That as a matter of fact our bromides were neutral there is no lack of evidence. The possibility of acidity had occurred to us also, but reasoning from analogy we had decided that this possibility was rather an improbability. Bromides and chlorides of barium and strontium, heated in the same way in a dry acid atmosphere, after the acid has been displaced by dry air, give absolutely neutral reactions with methyl orange.* With cobaltous bromide the end point is not as easy to detect as with the before mentioned halides on account of the color of the dissolved salt, but colorimetric comparison makes it possible to distinguish the change very accurately. A solution of our cobaltous bromide containing methyl orange perceptibly changed color upon the addition of the minimum amount of hundredth normal acid necessary to produce a change of color in pure water containing methyl orange, showing that the salt must have been very near if not at the turning point. As a final test, potassium

* These Proceedings, XXIX. 59, XXX. 373.

bromide was sublimed in the apparatus which had been used for the preparation of the cobaltous bromide. The sublimate was then heated in a current of dry nitrogen and hydrobromic acid gas, and finally, when cool, the nitrogen and acid were displaced by dry air, just as in preparing the cobaltous bromide for analysis. This potassic bromide upon solution gave an absolutely neutral reaction with methyl orange. Taking into consideration these three points, one cannot believe that enough hydrobromic acid was retained to have had an appreciable influence on our results.

The third criticism, objecting to the fact that in some analyses a small amount of nickelous oxide was found in the bromide, is an unfortunate one. A careful perusal of the work would have shown that only in the preliminary series of results was this the case, and that this series does not enter into the final average, although its results differ only by a very small amount from those subsequently obtained with material free from oxide. As far as the nickel is concerned, a conclusive proof of the absence of acid is afforded by this very fact that the earlier determinations, in which it was necessary to filter off a residue of finely divided nickelous oxide, gave results no higher for nickel than the later results.* Hence the second and the third criticisms are obviously inconsistent with one another.

The advantages of the Gooch crucible are too well known to need mention. Professor Winkler's specific objection to the collecting of displaced asbestos upon an ordinary filter affects only an amount of a few tenths of a milligram; and a proof that no error was introduced in this way lies in the fact that in every case the amount of silver bromide found agreed very closely with the amount of silver necessary to complete the reaction, where all but a few tenths of a per cent of the silver was weighed out, and the remainder was added volumetrically. The following brief table will make this clear.

Thus, in the cobalt work, 18.16302 grams of silver yielded 31.61642 grams of silver bromide, — a ratio of 57.448 to 100.000, — while in the case of nickel, 15.51556 grams of bromide gave 26.67078 grams of silver bromide, — a ratio of 57.444 to 100.000, while Stas found 57.445.

From the cobalt work	$AgBr : Ag = 100.000 : 57.448$
From the nickel work	$AgBr : Ag = 100.000 : 57.444$
From Stas's work	$AgBr : Ag = 100.000 : 57.445$

* The slight colloidal solubility of nickelous hydroxide was evidently destroyed by the presence of large amounts of nickelous bromide, as one would expect.

Thus the last of Professor Winkler's criticisms is sufficiently answered.

After necessarily dwelling at such length upon disagreements, it is a pleasure to emphasize other points in which we agree with Professor Winkler. The evidence of our work, together with Dr. Cushman's, strongly supports Winkler's contention that nickel and cobalt, as we knew them of old, cannot contain more than an infinitesimal amount of any unknown element. Several radically different methods of preparation and many fractionations invariably led us to constant atomic weights, within a reasonable limit of experimental error; and we are forced to conclude that the familiar properties of these common and useful metals are to be ascribed to elements as definite as any of the seventy-five. It is needless to point out also that we agree with Professor Winkler in assigning to cobalt a higher atomic weight than to nickel, in spite of the conflict of periodicity with rhodium and palladium. According to our results, the atom of cobalt, weighing almost exactly 59.00, is very nearly half of one per cent heavier than that of nickel.

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IV. — CONTRIBUTIONS FROM THE HARVARD MINERALOGICAL MUSEUM.

A COMPARATIVE STUDY OF ETCH-FIGURES. THE AMPHIBOLES AND PYROXENES.

BY R. A. DALY.

WITH FOUR PLATES.

A COMPARATIVE STUDY OF ETCH-FIGURES. THE AMPHIBOLES AND PYROXENES.

By R. A. Daly.

Presented by J. E. Wolff, December 14, 1898. Received January 18, 1899.

CONTENTS.

INTRODUCTION.

AMONG the larger groups of rock-forming silicates, there is none perhaps which, in the present state of our knowledge, offers more difficulties in the determination of systematic relationships than the amphibole family. Its importance for the petrographer needs no emphasizing here, yet it is he who has to meet the difficulties of classification and discussion under the most disadvantageous circumstances; in general, by reason of its association, the amphibole of an eruptive rock or of a crystalline schist lacks crystal form, and, because of numerous inclusions, it may often be impossible to procure a reliable chemical analysis of the mineral. Thus deprived of two principal aids to diagnosis, the worker in rock-forming amphiboles must make the most of the other criteria which offer themselves. In so doing, he may eventually be able to repay the pure mineralogist for his services to the study of the crystalline rocks and present new considerations that can lead to the interpretation of the mineral species as such without relation to rock genesis or rock classification. Of the methods which, so far, have been almost completely neglected by petrographers in the investigation of amphiboles, is that of the use of etch-figures on planes of the more important zones. I propose in the following pages to record briefly certain results I have obtained while breaking ground in this new field of inquiry.

The first, and so far as I have learned, the only published reference to actual experiments in etching an amphibole, occurs in Bořicky's first essay on microchemical methods.* Plate II. Fig. 7 of his work represents a hornblende etched with fluosilicic acid on the clinopinacoid. The reference in the text to this drawing was occupied with the mention of the chemical reaction, and especially of its products, — nothing further.

* Archiv d. naturw. Landesdurchforschung von Böhmen, III., Prague, 1877.

Sir David Brewster observed his "Optical Figures" on a few hornblendes characterized by natural pits of corrosion.* Since nothing has been done towards a comparative review of etching phenomena with respect to the amphiboles, I shall state some of the reasons why the present research was begun.

(1) In the first place, it has been considered a good opportunity to test once more how far etch-figures are dependent on the method of attack, and to devise a convenient and uniform method for the group in question. (2) Will the etching process furnish any information as to the attackability of amphiboles in hydrofluoric acid? (3) Are the etch-figures variable in shape with the chemical composition of the mineral? Will they throw any light on the problem of isomorphism among the amphiboles? (4) Will the amphibole figures by comparison with those on the corresponding faces of pyroxene, tend to strengthen the parallel between the two mineral groups? (5) Can cleavage pieces and crystals of amphibole be crystallographically oriented by means of etch-figures? (6) Will the latter give us any data on the vexed question of the best standard orientation of amphiboles as a whole? Is Tschermak's or Nordenskiöld's recommendation better fitted to disclose the many varied relationships of the group? (7) Are the amphiboles holohedral? (8) Are anthophyllite and gedrite really orthorhombic? (9) Incidentally, in connection with the attempt to solve these problems, I have compared etch-figures using hydrofluoric acid with those obtained with the corrosive alkalies.

Now, in order to pave the way for a concise description, and perhaps readier understanding of the following discussion, a few lines may be taken to define a certain number of terms which have been introduced with more or less technical import. Several of these are literal or slightly modified translations of the valuable German names or phrases of Becke, Baumhauer, Leydolt, and others.

The etch-figure itself may be a cavity of corrosion, an "etch-pit" ("pit of corrosion," Aetzgrübchen, Aetzvertiefung), or it may be an etch-hill (Aetzhügel), a residual boss standing up in relief above the general surface of the crystal. Either etch-pit or etch-hill is bounded by "figure-faces" † (Aetzflächen), in general manifestly plane, sometimes

* Phil. Mag., 1853, Vol. V., p. 16.

† Molengraaf's nomenclature seems unfortunate in relegating the short, useful word "Aetzfläche" to the comparatively unimportant curved surface which often truncates a crystal edge when exposed to corrosive agents, and compelling us to speak of the figure-face of a pit as an "internal etch-face" (innere Aetzfläche). — Zeit. für Kryst., 1888, Bd. XIV. p. 174.

apparently curved, faces. Many pits normally exhibit a figure-face parallel to the plane etched; it may be designated the "bottom-face." An "etch-zone" is a zone containing two or more figure-faces ("Aetz-zone" of Molengraaf, not equivalent with the "Aetzzone" of Becke). The periphery of the pit where its figure-faces intersect the plane attacked is here called the "outline" of the figure, and each "edge" that composes it may thus be a straight or curved line as its figure-face is plane or curved. A "corner" is the point where the etched plane and two adjacent figure-faces meet.

As the process of etching continues, a pit usually increases in size, often (depending partly on the symmetry of the etched plane) changes in shape of ontline, and, in many cases, deepens as the result of replacement of early formed figure-faces by others of different indices, accompanied by the necessary "diminishing" of the "bottom-face" if there be one present (cf. pits on apatite, calcite, galenite, gypsum, zinc-blende, etc.). These changes in the figures *may* be continuous, but often have rather the look of being intermittent, the replacement of one figure-face by another taking place as a momentary change, faces of intermediate indices not appearing at all. The first stage of development of a pit may be called its "initial" form. The development ends where the outline begins to be seriously impaired by the solution of the surrounding part of the etched surface. Just preceding this point in the history, the pit may be called "mature," and the process intervening between the initial and mature stages is that of "maturing." Von Ebner's "instantaneous" and "retarded" types are connected by transitions, but are not easily to be compared to "initial" and "mature" figures, since his types refer simply to the length of time required to develop the pits, and are not restricted to the use of one solvent.*

Discussion of Etch-Figures in the Microscope.

It is believed that a description of the etch-figures as seen in reflected light with vertical incidence would be, on the whole, of more value than an account of the same figures examined under other conditions (transmitted light, Lichtschimmer). Within certain limits, this method is easily carried out with the aid of the modern appliances to be found on the large models of most petrographical microscopes, and thus a new etch-figure can in a few minutes be compared in its main features with

* Sitzungsber. der Akad. d. Wissen., Vienna, 1885, Bd. XCI. p. 775

those already established for the corresponding face and mineral group, or with analogous figures belonging to other species. Furthermore, such a description may be made in cases where any determination of the indices of the figure-faces is impossible on account of the absence of "Licht-schimmer," due to various causes, as fibrosity, minuteness of figures, curvature of the surface studied, etc. But it is necessary to recognize that a complete analysis of a figure is not possible in many cases, even under the most favorable circumstances. This is true, for example, of the pits on the prismatic faces of amphibole and in the vertical zone of most monoclinic minerals. Relatively low powers of the microscope must always be used, since contrasts of dark and light are speedily lost above 200 diameters, and thus it often cannot be decided whether an apparently rounded figure-face may not really be one compounded of many small faces, according to the well known examples of Becke, Baumhauer, and others. Hence, inasmuch as it is not practicable to determine in the microscope the elements (faces, angles, symmetry, etc.) with the same precision and detail with which we can define a crystal, it becomes advisable to choose certain elements of the figure that are sufficient to fix its general shape. Such elements will be those which can be directly measured in the microscope and with a maximum of exactness. They will include straight sides and the angles between them as well as the special angles between curved sides characteristic of each figure. These elements, too, had best be such as can be recognized on very small figures of a given category, since in some varieties it may be feasible to produce figures only relatively very minute. Lastly, we must have a base-line of reference for all measurements; — in amphiboles, there is an excellent one, the trace of the cleavage, which generally makes it unnecessary to search out the directions of edges bounding the crystal-face.

For the convenient examination of figures on (110), it is well to use prisms with sides as smooth as possible, so that the mineral will lie flat, and the plane to be studied perpendicular to the axis of the microscope. In the study of terminal planes, or of material with which such perfect prisms are not obtainable, the crystal or cleavage piece may be readily brought into the desired position by mounting it on an object-glass with wax and then adjusting it so that the simultaneous reflection of a ray of light from the glass and the plane may occur. With lustrous faces, this adjustment can thus be carried out with a close degree of accuracy.

The microscope used was a Nachet, provided with an apparatus for vertical incidence of the light that illuminated the crystal-face. The light was led through a collimator attached to an Auer lamp. Below

the collimator, the metal casing of the lamp was pierced so as to allow of a source of transmitted light for getting extinctions in cleavage plates. Orientation could thus be effected by means of extinction (when the amphibole was known), as well as by using terminal planes.

For reasons explained further on, Tschermak's orientation is adhered to throughout this paper ($\beta = 73° 58'$).

The photographic illustrations I owe to the skill of M. Monpillard of Paris. The difficulties in reproducing anything like the sharpness of the etch-figures on amphiboles, especially on faces other than that of the fresh cleavage flake, are very great and fully explain any lack of definiteness that may be observed in the micro-photographs. The diagrammatic figures were drawn by means of a camera lucida and bring out more clearly than the photographs, the points of essential resemblance and dissimilarity which need emphasis.

Both in the diagrammatic figures and the wash-drawings of Plate I. the cleavage trace on each etched surface is represented by a straight line, which the reader will immediately recognize. This line is replaced in the photogravures by the longer edge of the page. The top of the crystal will as usual be directed toward the top of the page in the case of planes in the vertical zone; the front of the crystal toward the bottom of the page for terminal planes.

Materials of Study.

The work the results of which are embodied in the following pages was begun in the laboratory of Professor Rosenbusch at Heidelberg, where the initial experiments were carried on with crystals of Vesuvius hornblende obtained from the collection of the Mineralogical Institute, and with Zillerthal actinolite, St. Gothard (?) tremolite, and Bohemian hornblendes from the private collection of Professor V. Goldschmidt of Heidelberg. To this material were added 41 specimens from the Imperial Museum, Vienna, through the kindness of Professor Berwerth, some 20 others from the collection at the Jardin des Plantes, Paris, due to the liberality of Professor Lacroix, six fine crystals of aenigmatite and arfvedsonite from Professor Ussing, Copenhagen, classic glaucophane from Professor Barrois, Lille, and much American material from Professor Hobbs, Madison. To these gentlemen I should like to express my hearty thanks for the privilege of securing so many specimens with little trouble to myself, — material which in many cases is classic, and of considerable value from the mere monetary point of view. Without the use of so many representatives of the group, I should not have felt

enough confidence in the generalization from certain types to all types. The systematic investigation was almost entirely pursued in the laboratory of Professor Lacroix, and I desire to acknowledge, in particular, his generosity in placing at my disposal the apparatus necessary for the etching.

The list of specimens is self-explanatory. For convenience I have followed Dana's classification closely, without however implying an absolute adherence to all its details. I have inserted the catalogue numbers of the Museum specimens, sometimes the date of collection, and, where possible, leading references to original papers in connection with those specimens that have furnished particular descriptions or material practically identical with them. An asterisk denotes a specimen *presumably* similar to the classic material from the same locality. The source of each specimen is indicated in the general list by letters prefixed to the number corresponding. H. = Heidelberg, V. = Vienna, P. = Paris, C. = Copenhagen, M. = Madison, L. = Lille.

Amphiboles proper.

A. Orthorhombic amphiboles.

a Anthophyllite.

P. 1. Kongsberg, Norway: —
Des Cloiseaux, Nouv. Recherch., 1867, p. 541.
Michel Lévy and Lacroix, Min. des Roches, 1888, p. 149.

P. 2. Nunangiast, Greenland. — 20–125.

P. 3. Regardsheim, Norway.

b. Gedrite.

P. 4. Gèdres, France: —
Dufrénoy, Ann. des Mines, 1836, Vol. X. p. 582, etc.

B. Monoclinic Amphiboles.

a. Non-aluminous.

(1) Tremolite.

H. 5. St. Gothard (?).
P. 6. Siberia. — "Grammatite." — 2–855.
P. 7. Faroe Islands. — 64–63.
V. 8. Newport, Bucks Co., Mass. (?) A. c. 4154.
*M. 9. Gouverneur, N. Y.

(2) Actinolite (with certain allies).

*H. 10. Zillerthal.
*P. 11. "
P. 12. Syra.
P. 13. Gellivara, Asia Minor, 68–31.
V. 14. Killaersarbik, Greenland. A. e. 924, 1818.
V. 15. Anaitsirksarvik, Greenland. A. u. 98.
*V. 16. Orange Co., N. Y. E. 5606, 1888.
V. 17. Arendal, Norway. A. e. 961, 1825.

V. 18. Ottawa River, Canada. A. e. 968, 1826.
P. 19. (Smaragdite), Greenland.
*V. 20. (Richterite), Langban, Sweden. A. a. 509.
*V. 21. " " " G. 3122, 1894.
*V. 22. (Astochite), " " G. 4080, 1895.

(3) Cummingtonite.

*M. 23. Cummington, Mass.

(4) Grunerite.

P. 24. Collobrières, Dep. du Var, France: —
Lacroix, Bull. Soc. Min., 1886, p. 40.
Minéraux des Roches, 1888, p. 144.

b. Aluminous.

*P. 25. (Edenite) Edenville, N. Y. 64–145.
*V. 26. (Pargasite) Pargas, Finland. A. e. 928, 1848.
V. 27. " " " A. o. 469.
Berwerth, Sitzb. Akad. Vienna, 1882, Bd. LXXXV. p. 158.
*V. 28. (Pargasite). A. e. 929, 1826.
V. 29. (Carinthine) Saualpe, Carinthia. A. o. 464 and 465.
Tschermak, Min. und Petrog. Mittheil., 1871, p. 88.
*H. 30. (Syntagmatite of Breithaupt), Vesuvius.
*V. 31. Kragerö, Norway. G. 3287, 1894.
V. 32. Arendal, Norway. A. f. 2., 1827.
V. 33. " " A. e. 967.
V. 34. " " A. e. 891 and 892.
V. 35. " " A. e. 897.
V. 36. " " A. e. 898.
V. 37. " " A. o. 432.
V. 38. " " A. o. 434.
V. 39. " " A. f. 3, 1824.
V. 40. Norway. A. o. 459.
V. 41. Philipstad, Sweden. A. o. 458.
*V. 42. Kafveltorp, Sweden. 1889.
*V. 43. Wolfsberg, Bohemia (in basalt). A. a. 1860.
V. 44. Orbus, Kupferberg, Bohemia. A. o. 446.
*H. 45. Bilin, Bohemia.
V. 46. Mayenegg, near Kupferstein. B. e. 5378, 1838.
V. 47. Easton, Pennsylvania. A. e. 971, 1826.
V. 48. Worthington, Mass. A. e. 902, 1825.
V. 49. Kangerotvarsvik, Greenland. A. e. 922, 1818.
V. 50. Edenville, N. Y. (greenish-black). A. e. 913, 1829.
V. 51. " " (dark green). A. e. 901, 1827.
V. 52. Gebel Gharib, Arabia. B. d. 6369, 1877.
P. 53. (Gamsigradite) Gamsigrad, Servia. 97, 351.
Lacroix, Bull. Soc. Min., 1887, Vol. X. p. 147.
*V. 54. Wolfsberg, Bohemia (twin). F. 3850, 1890.
P. 55. Riveau Grand, Mont Dore.
Lacroix, Minéralogie de la France, 1893–95, Vol. I. p. 663.

Glaucophane.

*P. 56. Ile de Groix.
L. 57. " "
Barrois, Am. Soc. Géol. du Nord, 1883, p. 19.
P. 58. Oulx, Savoy.
*P. 59. (Gastaldite) Champ de Praz, Val d'Aosta. 90, 197.

Crossite.

*P. 60. Berkeley, Cal.

Riebeckite.

P. 61. St. Peter's Dome, Colorado. 89, 6.

Arfvedsonite.

*P. 62. Kangerdluarsuk, Greenland.
*C. 63. " "

(Barkevikite.)

*P. 64. Barkevik.

Aenigmatite.

*P. 65. Naujakasik, Greenland. 95–190.
*C. 66. " "

Bronzite.

*P. 67. Kraubat, Styria.
P. 68. Greenland. 9–25.

Hypersthene.

P. 69. St. Paul's Island. 85–2631.
Lacroix, Min. des Roches, 1888, p. 261.

Diopside.

*P. 70. Ala.

Augite.

P. 71. Puy de la Rodde.
Gonnard. Cf. Lacroix, Minéralogie de la France, Vol. 1, p. 578.

Fowlerite.

*P. 72. Franklin, New Jersey.

Methods Used.

The researches of recent years on figures of corrosion have shown that the most fruitful results are obtained by quantitative methods, that is, by the use of reagents under definite specified conditions, and by close measurement of the figures. It hardly needs mention that there is much yet to be learned regarding the cohesional properties of the species belonging to each of the great mineral groups, as well as regarding the similar relations which may exist between corresponding members of two different families. Just as we may describe as accurately as possible the hardness or the fusibility, the specific gravity or the optical properties, of a species, not only to fix it as an independent type, but also to relate it to the other members of its own family and to other mineral groups, so we believe it is possible to construct with

some precision a scale by means of which crystal faces may be defined as to molecular cohesions. This has, in fact, been accomplished in certain cases; but, in general, etch-figures have only been used *qualitatively*, so to speak, and as yet there has been not enough of continuity of method from one investigation to another to make possible detailed comparison of species with species in this matter of facial cohesion. In the particular case of the group here considered, it has seemed desirable to make it possible to reproduce the conditions finally selected for etching, so as to permit of the discussion of new amphiboles with the aid of data already in hand. May it not be possible that the contradictory results of certain observations is simply due to difference in methods? Thus, Penfield, Meyer, and Bömer found the basal plane of quartz characterized by etch-hills when hydrofluoric acid was used,* while with the same solvent Gill obtained pits of corrosion.† For these and other reasons noticed below, I have tried to establish a constant method which would give good results with all varieties of the great amphibole family, and one which can be extended to the pyroxenes and other silicates. That such a method be wrought out, it was necessary that some preliminary experiments should be made, for reasons, some very obvious, others less so, all of which I shall summarize in this connection.

1. It is generally advisable to choose prominent crystal-faces, usually those of simple indices and those parallel to cleavages. That one would select such faces is to be expected, but I think this point should be especially in mind if comparisons are to be made as widely as possible. An advantage in choosing cleavage pieces or the corresponding crystal-face is evident in those groups where certain members appear only as allotriomorphic individuals in rock aggregates. Even in these cases, their etch-figures may be produced on a good cleavage when figures on other planes would only be possible on artificial faces. Fortunately, too, for the discussion of rock-forming amphiboles as well as of the group as a whole, the cleavage pieces give the sharpest and most regularly developed figures to be obtained on any given crystal.‡ The prismatic cleavage of amphiboles has thus a superior claim to attention, and I have accordingly laid most stress on this important face in the course of the present investigation. Next to these, pinacoids will naturally give the most useful

* Trans. Connecticut Academy, 1889, p. 157. Neues Jahrb. für Min., etc., 1891, Beil. Bd. VII. p. 534.

† Zeit. für Kryst., Bd. XXII. p. 111.

‡ Cf. Baumhauer, Resultate der Aetzmethode, p. 8.

results. As a matter of fact, I have found (010) and (100) to be among the interesting faces for etching on amphiboles. Moreover, not only are they very common planes; they are also those most likely to reveal the fundamental features of crystal structure.

2. Since the production of etch-figures on a bisilicate is in large part the result of a chemical reaction between mineral and solvent, it is clear that the figure will, in every case, depend on the chemical nature of both. Two varieties apparently isomorphous and differing little in composition may afford figures markedly different from each other, although produced on planes with the same symbols and with the same solvent. Examples will be noted in the sequel. Such being the fact, it is natural to conclude that the figures shall be similarly sensitive to small changes in the solvent also.* A striking illustration is to be found in the series of etch-pits formed on (010) of actinolite by hydrofluoric acid in various states of dilution in water or mixture with sulphuric acid. There is a steady change in the orientation of the figure as the state of purity of the hydrofluoric acid is affected. Details concerning this phenomenon are given in the section devoted to a description of figures on (010).

I chose hydrofluoric acid as the universal attacking reagent on account of its convenience and efficiency. Inasmuch as its working depends on the degree of concentration of the acid, it becomes necessary to fix on some particular grade of acid. A number of trials soon convinced me that the concentrated commercial water solution is for general purposes the best. Not needing special preliminary preparation, it is easily obtainable in any desired quantity; experiment showed that it gave the most satisfactory figures just as the alums afford the best results with the solvent in an active state.† There is one danger to be guarded against, namely, the loss of concentration with prolonged heating of the acid; hence the advantage of easy renewal of the reagent.

Temperature and its function, the duration of immersion, are now well established to have a strong influence on the process and effects of etching. A new variable must thus be considered. As a result of a large number of trials made both incidentally and with this distinct purpose in mind, I found that good figures could be produced at many different temperatures; thus, Zillerthal actinolite will yield well developed pits of corrosion when boiled one minute in HF, or at three minutes in HF

* Cf. Von Kobell, Sitzungsber. Münchner Akad., 1862, p. 199; Ben Saude, Ueber den Perowskit, Göttingen, 1881; Meyer, Neues Jahrbuch, 1883, Bd. I. p. 77.

† Klocke, Zeit. für Kryst., 1877-78, Bd. II. p. 180.

on a water bath, or, again, when immersed several hours in cold HF. Among all these possibilities I have endeavored to secure for all comparative studies a temperature as nearly constant as possible, and this for two reasons. In the first place, it would not be at all certain without direct proof that the figures with any one reagent remain constant for all temperatures. Bömer discovered that the form and orientation of the figures on quartz produced by attack with HF were affected by the temperature of the reaction.* It is reasonable to suppose that temperature may have a corresponding effect on amphibole figures when the same reagent is used. As will be noticed elsewhere, I have been able to determine no sensible variations in figures on (110) from this cause, but it cannot be denied that they are present. Secondly, I wished to tabulate the amphiboles with reference to their power of resisting solution in the etching process. The standard temperature chosen for these reasons is that of the water bath, one that is nearly constant, attained with no difficulty, and found to suit the necessities of the case very well.

To secure a standard temperature for the reaction repeatedly and expeditiously demanded in addition a certain amount of arbitrary treatment, since the amount and initial temperature of the acid have not yet been allowed for. A platinum crucible of the usual slightly conical form and with a diameter at the bottom of about 4 cm. is filled to a depth of 1 cm. with the cold acid; the mineral, resting in a platinum net, is immersed, and at the same time the crucible is placed 1 cm. deep in the steam of a water-bath which is kept constantly at 100 degrees Centigrade. The attack is readily checked at any moment by lifting the platinum net and plunging it with the mineral into water. The coating of fluorides could be readily removed by brushing the mineral in running water, or by dissolving them in hot concentrated hydrochloric acid.

Another point of inquiry in connection with formation of an ideal method would be the effect of increasing the energy of the reaction by the agitation of the acid during attack. Klocke, in his classic research on the alums, found that on agitating the solution in which corrosion pits were forming, the figures grew larger rapidly, due, as he stated, to the dissipation of the "Hof" (Lösungshof) of liquor near the figure which had become laden with the products of solution.† Experiment of the same kind was carried on with basaltic hornblende, but no material improvement was effected on the sharpness of figures produced without

* Neues Jahrbuch, 1891, Beil. Bd. VII. p. 538.
† Zeit. für Kryst., 1877-78, Bd. II. p. 298.

agitation. I am inclined to think that convection currents in the warmed acid are sufficient to perform the same function.

In thus fixing on a universal solvent, its temperature, state of concentration and of convention, we have narrowed down the variables of the process to one, the duration of attack. This facility in arriving at the conditions of a uniform method of etching is not possible when the caustic alkalies are employed and hence these will be referred to only incidentally in the following pages. Unless the contrary be stated, the standard conditions of etching are to be understood in every experiment.

The Optimum Exposure of the Different Species.

Here the study was confined to cleavage pieces. It was naturally found that as the figures increased in number, they also increased in size, any changes in shape not being sufficient to remove them from the category of "primary" figures (Becke). In most cases, the general cleavage surface showed no serious roughening as the figures grew and the attack was allowed to continue nearly to the point where overlapping of the pits (generally aggregated in groups) would occur. This length of exposure usually gave the best figures for study; hence I have called it the "optimum" duration of attack. Since the determination of the optimum length of immersion was a matter of considerable labor, the result of several trials with almost all varieties, I have thought it worth while to tabulate the results obtained with a certain number of specimens. It is to be understood that the following table is only approximately accurate. Perfectly fresh acid was not used in every case, and, of course, the longer the acid remains on the water bath, the weaker it becomes; moreover, the amount of steam in the water bath is variable to some extent, and thus the HF might become heated at different rates. Care was taken to allow for such causes of variation from the true optimum.

Optimum Exposures.

Anthophyllite.	
P. 1 . . .	2 minutes.
P. 2 . . .	2 "
Gedrite.	
P. 4 . . .	2 "
Tremolite.	
H. 5 . . .	8 "
V. 8 . . .	3 "
Actinolite and allies.	
H. 10 . . .	2½ "
P. 11 . . .	2½ minutes.
P. 12 . . .	2½ "
P. 13 . . .	1 "
V. 14 . . .	4 "
V. 15 . . .	1½ "
V. 16 . . .	2 "
V. 17 . . .	2½ "
V. 18 . . .	1 "
P. 19 . . .	1½ m. (Smaragdite).
V. 20 . . .	¾ m. (Richterite).

V. 21	¾ m. (Richterite).	
V. 21	1¾ m.	"
(another specimen).		
V. 22	1 m. (Astochite).	
Common and basaltic Hornblende.		
P. 25	2½ m. (Edenite).	
V. 26	2½–3 m. (Pargasite).	
V. 27	" m.	"
V. 28	" m.	"
V. 29	2 m. (Carinthine).	
H. 30	½ m. ("Syntagmatite").	
V. 31	1½ minutes.	
V. 32	1¾	"
V. 33	1¼	"
V. 34	1	"
V. 36	⅓	"
V. 37	½	"
V. 39	1	"
V. 40	1	"
V. 41	1½	"
V. 42	1	"
V. 43	2½	"
V. 44	¼ minutes.	
V. 46	2½	"
V. 48	3	"
V. 49	2	"
V. 50	1	"
V. 51	1	"
V. 52	¾	"
P. 53	1 (Gamsigradite).	
Glaucophane.		
P. 56	2 minutes.	
P. 58	(?) 1½	"
P. 59	1½	"
Riebeckite.		
P. 61	¾	"
Arfvedsonite.		
P. 62	½	"
(Barkevikite).		
P. 64	½	"
Aenigmatite.		
P. 65	⅓	"
C. 66	⅓	"

The average optimum exposure of these groups as indicated by the optimum exposure can, then, be expressed somewhat as follows: —

Anthophyllite	2	minutes.
Gedrite	2	"
Tremolite	3	"
Actinolite	2	"
Richterite	1	"
Astochite	1	"
Edenite	2½	"
Pargasite	2¾	"
Common and basaltic hornblende	1¼	"
Glaucophane	1¾	"
Riebeckite	¾	"
Arfvedsonite	½	"
Barkevikite	½	"
Aenigmatite	⅓	"

Attackability of the Amphiboles.

Referring as they do to the appearance of best figures on the prismatic cleavage, without regard to their size, these tables do not express the attackability of the various species. Thus the average time for the development of the sharpest figures on anthophyllite and actinolite is in

each case, two minutes, yet the actual amount of material carried off in solution from the very minute pits of the anthophyllite is extremely small when compared with that removed in the process of excavating the much larger pits on the monoclinic mineral. While working out optimum exposures, I generally had opportunity to observe the incipient stages of attack on cleavage-cracks and of the roughening of the whole surface of the crystal. In this way a general impression of the relative attackability of these minerals was gradually made upon me. I give the series for what it is worth, beginning with the varieties most resistant to hydrofluoric acid, and naming the others in order of less resistance: — 1. The orthorhombic amphiboles. 2. Actinolite. 3. Tremolite. 4. Glaucophane. 5. The light-colored aluminous monoclinics. 6. The common green hornblendes. 7. The basaltic hornblendes. 8. The Richterites. 9. Arfvedsonite. 10. Riebeckite (?). 11. Aenigmatite. It will be seen that the resistance to solution decreases with increase in soda and in sesquioxide of iron.

But not only are the differences of attackability due to differences in chemical composition and crystal system, they are also strongly affected by physical conditions irrespective of species. The physical influences may entirely mask the attackability resulting from the chemical reaction alone. The theories which have been made to explain the irregular distribution of etch-figures on a given plane by corresponding irregularities in the grouping of the chemically active part of the solvent in use, can have no application to many cases that have come under my notice during the course of the present research. They are often rather to be explained as dependent on a loosening of the original molecular structure of the mineral by mechanical action without at the same time being accompanied by chemical decomposition. The presence of submicroscopic cracks or planes of parting (a superficial capillary zone) will necessarily give the acid greater surface by which to attack and permit of a readier dislodgment of the molecules from the grip of physical cohesion. A good analogy is found in the hardness of certain pseudomorphs; manganite with a hardness of 6 forms a pseudomorph after polianite (pyrolusite), but has then an apparent hardness of only 3.

A few typical examples of this differential resistance to solution will suffice for our present purpose. Two intergrown crystals of V. 42 apparently of equal freshness, each bearing the plane (011), were simultaneously immersed for several periods and examined at the end of each interval for the relative progress of attack. The plane (011) of one crystal was seen to have been affected decidedly *sooner* than the same

plane of the other. In this case, the ready yielding of the former may have been caused by its being exposed to more active convection currents than the second crystal, due to position in the acid. But this explanation cannot apply to V. 46, where the optimum exposures for cleavage flakes from different crystals, though from the same hand specimen, varied from two and one half to five minutes, and the pits were of nearly equal size (area and depth) on all the pieces. V. 34 afforded some light on the question in the behavior of two terminated crystals, the (011) of the one, less lustrous than the same plane of the other, was the more rapidly attacked. The suggestion that the phenomenon is a result of alteration can hardly be avoided. That the alteration may be an almost, if not quite, exclusively physical one and not associated with a serious change in the original chemical molecule of the hornblende, seems clear from the facts observed in an experiment on V. 31. The hand specimen is a "Krystallstock" composed of well defined individuals, tipped with asbestus and occasionally showing patches of an asbestiform substance on the sides of the crystals. At two minutes' exposure, one of these gave sharp but relatively few figures on (110) near the point of attachment at the end of the crystal. The other three fourths of the surface of the prism was characterised by the appearance of numerous cleavage cracks which gradually increased in number in the direction of the free (in the druse unattached) end, and there was a simultaneous increase in the number of pits. The development of the latter was independent of the asbestiform patches, and, from the uniformity of color of the general surface, I have concluded that there has not been chemical decomposition sufficient to explain the differing rates of etching. It may be noted that the much attacked end was directed *upward* in the acid, and any heating by direct contact with the platinum at the bottom of the crucible would tend to dissolve the unaltered extremity of the crystal the more rapidly.

As a general rule, the crystal-face (110) was observed to be less resistant to solution than the parallel cleavage plates of the same individual crystal, but the converse was often true.* Thus at one and two thirds minutes, the cleavage showed much stronger attack than the corresponding crystal surface (110) of a specimen of V. 32, although here again the original face was facing downward, the cleavage plane upward, in the acid solution. The mineral was perfectly fresh in appearance, and betrayed no alteration to the eye such as seemed best to explain the same relations characterizing other examples: e.g. V. 8, V. 14, V. 17, V. 26, V. 42.

* Cf. Becke's experience with zinc blende, Min. und Petrog. Mitth., 1883, Bd. V. p. 485.

In these cases, actual separation had taken place along the cleavage planes in question long enough before the specimens were collected in the field to have permitted the physical processes of weathering to destroy to some extent the original cohesion of those layers of the crystals, while, for some reason (probably the protection of surrounding minerals), the crystal-face escaped such disintegration. That there may be other and more obscure physical differences which can explain the grouping of etch-figures was suggested by Baumhauer, who attributes the zonal arrangement of the pits on etched fluorites to them rather than to chemical variations in the zones.* The same principle is illustrated in the explanation of "Aetzgräben," † linear aggregations of pits following directions of weak cohesional control. Thus, on etched cleavage plates, there are commonly to be observed a regular grouping of figures in directions which are crystallographically fixed on hornblende; long rows of pits parallel to the trace of the second vertical cleavage, or to the trace of the rudimentary basal cleavage, without, in either case, there being actual cleavage cracks opened which would affect the etching directly. Viola has recently described the zonal distribution of pits on gypsum, the zones being regularly fixed with reference to the axis of symmetry.‡ Whether these zones represent the original stratification of molecular deposition or are the result of secondary physical change, acting on a homogeneous crystalline mass, the behavior of gypsum is another example with those already cited to show the dependence of attackability on physical cohesion, when the latter varies according to the laws of crystal structure. Incipient weathering and the development of secondary strains will favor an irregular grouping of etch-figures that are structurally accidental. These have been noticed in connection with the amphiboles. These facts lead us to suspect that Ebner's hypothesis of irregularities in the solvent can no better explain the differing attackability of a cleavage piece of calcite in its various parts than the hypothesis of varying physical conditions in the crystal itself. §

* Resultate der Aetzmethode, p. 6. Mere heating may render actinolite fibrous. See Doelter and Hussak, Neues Jahrbuch, 1884, Bd. I. p. 24.

† Ibid., p. 6.

‡ Zeit. für Kryst., 1897, Bd. XXVIII. p. 575.

§ That no *one* theoretical cause yet adduced in explanations will suffice is clear. Minute fracturings cannot, for example, pave the way for unequal etching in the case of a *growing* crystal of alum in a saturated alum solution. It is simply necessary to dilute the solution slightly in order to etch the newly made surface; here there could be no reasonable supposition that the crystal had already undergone any disintegration, yet the pits are irregularly dispersed on the surface. See

Having traced the influence of chemical composition and of physical conditions on the property of attackability, we may now proceed to inquire whether the single planes of an amphibole have different powers of resisting solution in hydrofluoric acid. I shall once more use the information gained in the process of etching; the appearance of figures and the loss of illumination using vertically incident light will be taken as the criterion of attack. Actinolite, tremolite, and common hornblende were thus examined.

A crystal of V. 42 was exposed first, 40 seconds, then one minute. At 40 seconds $(\bar{1}11)$ was visibly roughened but showed no figures, while (110) remained practically intact; at the end of the second exposure *both* planes were equally provided with pits. From the mere development of figures, it would appear that $(\bar{1}11)$ and (110) were of about equal attackability, but the roughening of surface gave much more reliable indications of the fact. Combining with this, the observations on the other faces, the series is correctly written in the order of increasing resistance to the acid $(\bar{1}11)$, $(011) \left\{ \begin{matrix} (100) \\ (010) \\ (110) \end{matrix} \right\}$. As a matter of fact, the maturing of pits on the various faces often occurred at intervals so far apart as to permit of a pretty tolerable determination of the facial attackability by means of their study alone. It is essential, of course, to distinguish etch-pits from etch-hills, which may (as described by Becke) simultaneously appear on two different faces of the same crystal. A generalization was made from the study of twelve crystals of aluminous hornblendes, as follows: V. 26, V. 32 (2), V. 33, V. 35, V. 40 (2), V. 42 (3), V. 54, and P. 55. Arranging the planes in order of increasing resistance to the acid, we have, $(\bar{1}11)$, (011), (130), (100), (010), (110). But what has been said about the phenomenon as affecting the corrosion on (110) applies with equal force to the other planes. With V. 54, I obtained the series $(\bar{1}01)$, (010), (110), (011), in the same order as above, — an anomalous order which I could see was correlated with the lustre and general state of repair of each of the faces belonging to the crystal in question. By reason of the peculiar geological conditions, and of the position of the crystal in its druse, a prism face may suffer alteration while an end face may escape that process and the latter can thus resist an attacking acid longer, though, as we have seen, the terminal planes are regularly the ones to yield first.

Klocke, Zeit für Kryst., 1877, Bd. II. p. 128. Cf. Retgers, Zeit. für Phys. Chemie, 1895, Bd. XVI. p. 638.

Similar results were found with crystals of Actinolite (V. 16), (V. 17), and of tremolitic amphibole (V. 8). The series are, respectively, ($\bar{1}01$), (011), (100), (110), and (011), (010), (110).*

These conclusions illustrate the now well established method of interpreting molecular structure by solubility in different crystallographic directions.† The series of facial attackability correspond to the dimensional variations in the pits on the various faces of an amphibole. They explain, for example, the very general elongate form of the pits on planes of the prism zone, an elongation in a vertical sense and coupled with a greater resisting power in the prism zone itself. I may further note, in passing, that here the different zones behave, as always, in a way to indicate the holohedral character of all the amphiboles. The "Lösungsoberfläche" (Becke) of amphiboles is monosymmetric and centrosymmetric.

Description of the Etch-Figures.

We may now proceed to the characterization of the etch-figures themselves. It has been thought most convenient, and as tending towards an easier survey of the facts, to group them with reference to crystallographic planes primarily and to consider in order the behavior of each species on etching each of these planes with hydrofluoric acid. We may hope thus to lessen the repetition of detail necessary in some degree; at the same time, the essential features of likeness or unlikeness of the different varieties will appear with most clearness. Following this more or less bald statement of fact, which is abbreviated as far as consistent with our immediate aims, there will be an attempt to correlate the facts both in way of summary review and as related to certain others which shall be especially introduced in the general discussion.

Etch-Figures on (110). *Actinolite Type.*

Throughout the whole series of non-aluminous amphiboles (excepting riebeckite) which I have yet studied (actinolite, tremolite, smaragdite, richterite, astochite, etc.), cleavage pieces give figures that are practically

* One fresh crystal of Zillerthal actinolite etched with an *alkali*, caustic soda, displayed greater resistance to attack on (010) than on (110). This may be another illustration of the rule enunciated by Baumhauer, that, in certain cases, the directions of rapid solution are reversed for acids and alkalies. Thus, he found it to be true for Linneite when he compared its behavior in the process of etching using nitric acid with its behavior in Becke's experiment of etching with caustic potash (Resultate der Aetzmethode, p. 20). The same holds true for magnetite (Ibid., p. 27).

† Cf. Baumhauer, Resultate der Aetzmethode, p. v.

indistinguishable from one another. They are the same as those on the corresponding crystal-face and are, so far as observed, uniform in characters for all strengths of acid and times of exposure. This does not imply that there are no differences in the figures, but these are so minute as, in most cases, to defy measurement. Since I obtained the largest and best pits on actinolite, I shall call theirs the "actinolite" type of etch-pit.

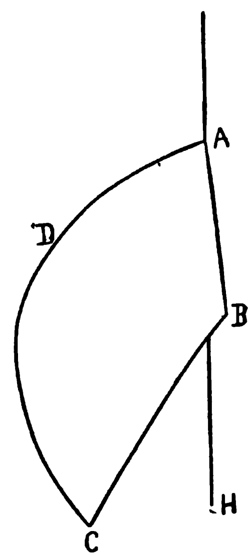

FIGURE 1.

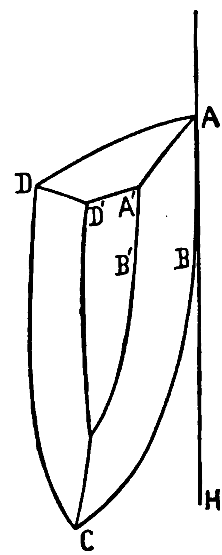

FIGURE 2.

In the diagrams (Fig. 1), (Plate I. Fig. 2), and Photograph 1, it will be at once seen that in the claw-shaped figure, there are not many elements which can permit of precise measurement and of the comparison of one figure with another, and with those of the aluminous amphiboles. Yet the shape is so constant as to render possible an immediate recognition of these figures and of their orientation. The etch-faces are generally three in number (sometimes four, as in Plate I. Fig. 4), one plane, the others more or less curved. The drawing and photograph convey a far better idea of the arrangement of the etch-faces than could be given in a verbal description, and it will only be necessary to note a few special points. First, we have the corner at *A* (Fig. 1), which is always the most clearly defined part of the figure. Often in the initial stage of development this re-entrant angle appears before one can make out any-

thing of the rest of the figure (Plate I. Fig. 1), a phenomenon that seems to have its correlative in the filling of the deeper parts, first of the figures on a crystal of alum when it is placed in a concentrated solution of its own substance (Ausheilen).* The edge $A\,B$ is likewise the most sharply outlined edge. The angle $B\,A\,H$ which it makes with the trace of the cleavage can be seen to alter as the figure gradually evolves in the process of etching. Thus, on Zillerthal actinolite, this angle increases as the figure grows more mature, from minus 2° to plus 10°, plus angles being read on the right of the cleavage trace passing through A (compare in Plate I. Fig. 1, Fig. 2, and Fig. 3). The limits of variation are the same for the Syra actinolite. In the actinolite numbered V. 14, they are 0° and 12°; in V. 16, 0° and 8°. During this process of swivelling, the edge AB remains straight; this suggests an actual change in the indices of the figure-face adjoining $A\,B$ as the pit is deepened, rather than a modification of a figure-face of constant indices by secondary solution. An analogous feature characterizes the pits on aluminous amphibole, as will be noted further on. Again, the corner at C, while not definite enough to allow of exact location as a point, can be with low powers so fixed with reference to A and the trace of the cleavage as to orient immediately the whole figure. Measurements were made of the angle CAH, within about 2° of accuracy in each case, as follows: —

Specimen.	Angle CAH.
H. 5	12°.
H. 10	13°–16°.
V. 12	13°.
V. 14	10°.
V. 16	12°–14°.
V. 17	12½°
P. 19	13°–15°.
V. 20	13°.
V. 22	13°.

This angle is then seen to vary only slightly, and it has always the same sign with respect to the trace of the cleavage. We may thus state the orientation of the pit by means of its longer axis $A\,C$; — the point of the "claw" is directed towards the positive hemipyramids. Furthermore, the asymmetry of the figure expressed in the contrast of the curved side ADC and the side AB gives the orientation at a moment's glance.

* Cf. Klocke, Zeit. für Kryst., 1877–78, Bd. II. p. 144.

Strongly attacked Zillerthal actinolite regularly exhibits normal etch-hills on the prism, but, since they are not of immediate interest in connection with our main purposes, I shall pass them over with this mere mention.

MONOCLINIC ALUMINOUS AMPHIBOLES. ETCH–FIGURES ON (110).

As might have been expected, I have observed a considerably greater variety in the aluminous amphiboles than in the relatively few non-aluminous species that, so far, have yielded figures that can be discussed. The pits of corrosion are, however, reducible to three types, respectively characteristic of basaltic hornblende, glaucophane, and arfvedsonite, and it is by the names of these species that we shall know the types.

The Hornblende Type (110).

To use an expressive German designation, the term "hornblende" is a "Sachname," and signifies a large number of bisilicates which are as yet not dignified by more specific names because of our ignorance of their real nature. If the phenomena of etching are to have weight in the discussion of the isomorphism or the orientation of cleavage pieces of hornblendes, it is expedient to examine an extensive and representative suite of specimens from the different members of the group, and determine what are the variations in the figures of corrosion along the series. I have accordingly etched about one hundred crystals and cleavage plates from the thirty localities mentioned in the list of materials used. The result was to show that all these species will give etch-pits whose main characters are constant, but permit of the recognition of at least four sub-types. From the localities of specimens that illustrate them best, these may be called the Wolfsberg, the Kragerö, the Edenville, and the Philipstad sub-types. With the exception of the last, crystal-face (110) and cleavage (110) give invariably the same figure.

The Wolfsberg Sub-type of Corrosion Pits on (110).

The front positive prism-face on the lustrous basaltic hornblendes of Norway, Bohemia, Vesuvius, etc., uniformly give an etch-pit, scalene-triangular in shape, with the most acute angle (corner) pointing downwards and the next most obtuse angle (corner) pointing northeast (Fig. 2, Plate I. Figs. 5, 6, 7, and 8). In a mature figure (Fig. 2), the three figure-

faces and the edges are curved, AC more than AD and DC more than AC. AB is a part of AC which is practically straight, but of variable length when compared to the pit as a whole. A, B, C, and D being the principal angular points of the figure on the outside, i. e. marking the more or less clearly defined corners formed by the meeting of pairs of figure-faces and the prism-face etched, A', B', and D' are corresponding corners at the bottom of the pit. Their position changes with the maturing of the figure, but they are always analogous to A, B, and D, because the bottom figure-face remains parallel to (110). To get some idea of the relative dimensions of the pits we shall define the "length" of a figure as the distance, AH, from A to the foot of the perpendicular running from C to the trace of the cleavage passing through A. The "breadth" is, in like manner, the distance from this trace to the line tangent to the curved side DC and parallel to the cleavage AH. The maximum length observed was about one tenth of a millimeter and the breadth never far from one third of the length. The angle $D' A' B'$ gives an indication of the bluntness of the figure, and is selected for measurement rather than DAB on account of its greater sharpness, and hence the greater accuracy in measurement. It is strikingly constant at from 72° to 73°. The angle CAH is of course variable with the elongation of the figure, but preserves a north by east trend in all cases. Its value is usually from 13° to 15°.

The angle BAH also helps to orient the figure, and displays an interesting relation to the deepening of the pit. The shallow initial pits of V. 46 characteristically had a large value for this angle (= 5°); as they matured, it passed through intermediate values until parallelism of AB with the trace of the cleavage was reached; there the swivelling of AB seems to have been arrested in even much older figures, and thus the angle BAH never was observed to change its sign. A cause for this swinging of AB is problematical, but it looks as if Becke's * principle of differential solution might be used in explanation. In the corner A, there is likely to be more rapid saturation with the products of solution than along the medial part of the figure-face AC, since these are not so readily whisked away in convection currents acting on the constricted parts of the pit as in those affecting the more open region about the point B, for example. Thus, the middle part of AC will suffer in a unit of time the attack of a greater number of chemically active ions than will the corners, and yield faster to solution accordingly. Such

* Min. und petrog. Mittheil., 1885, Bd. VII. p. 240.

a hypothecated process of "secondary solution" was incidentally referred to in connection with the actinolite figures; its effects can often be seen where straight-edged outlines of a figure are replaced by curved edges as the figure is undergoing destruction by prolonged solution.

Plate I. Fig. 7 furnishes a noteworthy variation on the normal and simple process of pit development. The figure is compound, and consists of three pits, formed respectively at the bottom of the next oldest pit. Each must represent an abrupt stage in the solution of this part of the surface. The side AD remains sensibly parallel to itself in all three steps, but the angle BAH grows larger from the first to the third numbered downwards; at the same time, the edges of the successive figure-faces against (110) are seen to curve more in the first than in the second, and in the second than in the third. These facts accord with those observed in the case of the pits that grew continuously, not intermittently, to maturity from the initial and less advanced stages of previous exposures to the acid. The stepped figure seems, then, to show that the formation of pits may (though not always) take place spasmodically, so to speak ("sprungweise," in the German phrasing), the attack the affair of a moment and preceded and followed by longer periods of almost perfect quiescence as regards other than "secondary" solution. Klocke believed, similarly, that the formation of figures on the alums is an instantaneous thing.* The stepped form is presumably not due to a zonal structure in the hornblende, because such a hypothesis would imply very considerable variations in the attackability in passing from the exterior to the inner zones of the crystal, — variations improbable

* Zeit. für Kryst., 1877-78, Bd. II. p. 131. The rapidity of the reverse process, that of healing over an etched surface, was early commented upon by Sir David Brewster in connection with his studies on the instructive group of crystalline substances, the alums, especially with reference to his now familiar "light-figures." On immersing an etched crystal of an alum in a concentrated solution of its own substance, he observed that, "in an instant," the pits of corrosion began to fill. He says, "The singular fact in this experiment is the inconceivable rapidity with which the particles in the solution fly into their proper places upon the disintegrated surface and become a permanent portion of the solid crystal." Phil. Mag., 1853, Vol. V. p. 27. The intermittent character of the process of etching was noticed by Rinne (Neues Jahrbuch, 1885, Bd. II. p. 15), who etched milarite with dilute HF. At first, the base became covered with regular hexagonal pits placed symmetrically on (0001). On further attack, these are *suddenly* modified by the appearance in each case of a second hexagon in the bottom of the first, but now turned through an angle of 30°.

and not yet shown to exist. The interrupted phases of solution are more reasonably connected with the lamellation of the cleavage parallel to the plane attacked. Actual microscopic or submicroscopic separation of layers parallel to this cleavage would present to the solvent action of the hydrofluoric acid a series of thin plates each of which, strongly resistant in a direction at right angles to the broad flat surface, would readily yield in directions *in* that surface, i. e. along the grain of the mineral.

The above mentioned data regarding the highly important Wolfsberg sub-type refer to conditions of etching described as standard for the present investigation. Remembering Bömer's conclusion that the temperature of the solvent has, in the case of HF and quartz, an influence on the figures, I have recorded the facts from a number of experiments intended to test the principle in its application to the group of the common and basaltic hornblendes. The experiments were made on V. 46, as follows: —

	Temperature.	Duration of Exposure.	Result.
(1)	HF boiling on Bunsen burner.	45 seconds.	Many poorly defined pits.
(2)	" " "	90 "	Larger poorly defined pits.
(3)	Water bath at 100° C. Standard conditions.	2 minutes.	Small sharply defined pits.
(4)	" "	2½ minutes	Pits numerous, in every case, some of great sharpness and large enough to measure.
(5)	" "	3 "	
(6)	" "	3½ "	
(7)	" "	5 "	
(8)	" "	8 "	
(9)	Acid slightly warmed.	10 "	Pits indistinguishable from the last, but associated with etch-hills.
(10)	" "	20 "	
(11)	Room temperature	16 hours	Few but good figures of the foregoing type.

Throughout the whole series there is such a close correspondence in the forms and measurements of the figures that we must posit for the latter an independence of the temperature of the hydrofluoric acid, so far as any *sensible* differences are concerned.

Neither temperature nor concentration of acid, nor, indeed, any cause known to me will explain a notable variation in the shape of the pits on (110) of the amphiboles now under consideration. It consists in the appearance of an adventitious fourth figure-face on the southeast side, in addition to the three usual ones (see Plate I. Fig. 8). There is no

discoverable rule governing its development, and I even doubt that it is always the *same* face. We might suppose that *B C* is composed of a large number of minute planes, and that, for some at present unknown reason, there is a selection of now one, now another, of these multitudinous facets, which grows rapidly and becomes prominent as a fourth figure-face of the pit.

Pargasite, carinthine, gamsigradite, syntagmatite, and barkevikite (see Plate I. Fig. 20), each from its classic locality, give figures that are equivalent with those just described for basaltic hornblende. The differences, if any, from the Wolfsberg sub-type are so slight as to prevent any determination of these varieties from the shapes of their respective corrosion pits. The other three sub-types merit a few remarks, inasmuch as they undoubtedly owe their distinctive characters primarily to chemical composition.

The Kragerö Sub-type, (110).

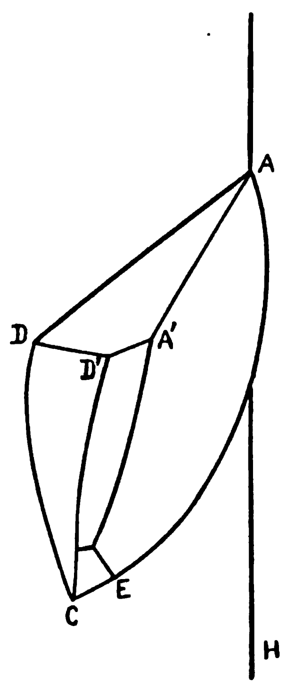

FIGURE 3.

The pits on (110) of V. 31 were somewhat sharper than those usually obtainable on basaltic hornblende (Figure 3, Plate I. Figs. 9 and 10, and Photograph 2). There are again normally three, abnormally four, figure-faces all oriented in the *sense* of the corresponding faces of the pits of the Wolfsberg sub-type. The straightness of the edge *A D* is here characteristic. The angle *D A H* is extraordinarily variable, having the value of about 38° in the initial figures, and intermediate values up to 80° in the large matured pits. There is also a swivelling of the edge *A′, D′*, but its amount is difficult to determine. Accompanying these changes in the figure-faces, there is a tendency for the figure to broaden out as it deepens; so that, while in the initial figures the ratio of length to breadth is about 3.5 : 1 (0.05 mm. : 0.014 mm.), that ratio is 2 : 1 (0.072 mm. : 0.036 mm.) in the matured pit. The angle *C A H* ranges through limits about equal to the Wolfsberg readings.

The Kragerö sub-type differs, then, from the Wolfsberg sub-type in the lack of curvature in the figure-face $A\,D\,D\,A'$, in the acuteness of the northeast angle at A, in the greater variation of shape as the figure grows older, and in the stoutness of the figure in plan. The orientation is the same in both, as also the occurrence of the adventitious fourth figure-face adjoining $C\,E$ in the figure (see Plate I. Fig. 10). V. 42 is the only other amphibole that showed closely similar etching phenomena (Plate I. Figs. 11 and 12, and Photograph 3), but their clearness has led to the conclusion that we have here a new category of figures whose explanation should be looked for in the internal structure of the varieties in question. The lack of analyses forbids the extension of this hypothesis.

The Edenville Sub-type, (110).

Edenite gave abundant figures, apparently identical with those on the Wolfsberg hornblende, but the habit of a cleavage piece of the former was peculiar in exibiting a general predominance of the four-sided figures already noted in connection with the previous two sub-types (Plate I. Figs. 13 and 14). The triangular figures do occur, but their number is quite subordinate. Even without their aid, it is very easy to orient cleavage plates of the mineral by means of fairly well developed quadrilateral figures; in them, the upper end is always recognizable.

The Philipstad Sub-type, (110).

The last of the hornblende sub-types which we have to notice is of special interest, since it led at once to further investigation and the discovery of a new and interesting variety of amphibole. Figures were produced on four different crystals, with exposures of 2 min., 2 min., 1¼ min., and 2 min., respectively, and on another crystal immersed in hot HF (near its boiling point) for one minute. In all five, the result was the same, two clearly defined figures, whose distribution was at first a mystery; on further study it was found that one type was confined to the cleavage faces and the other to the crystal faces, or to cleavage surfaces lying not more than 1 mm. beneath the latter. We begin with a description of the first mentioned sort of figures.

They vary in number of sides, in tint (proportion and distribution of light and shade), and considerably in shape (Photographs 6 and 7). Usually, they are six- or seven-sided and bounded by nearly or quite straight edges (Photograph 6), and either uniformly dark or more or less brilliantly illuminated on certain figure-faces. I could get no satisfactory

idea as to the relative steepness of the figure-faces on account of the great variability of the pits, on the one hand, and, on the other, the deep tint characteristic of the pits. The largest mature pits are perfectly black, blunt on the upper end because of the truncation by a long transverse edge and bulging below but tapering rapidly to the lower end. The angle made by the transverse edge with the cleavage trace was measured at 83°, a value which lies within the limiting values of the angle *D A H*, in Figure 2; the edge is thus oriented the same as the edge *D A* of the Wolfsberg sub-type, and the two are regarded as equivalent.

Now, these pits appear on all four cleavage faces and are also associated on these according to the law of twinning after (100); but with them were found a second set of pits arranged enantiomorphously to the first. Evidently, no system of twinning can explain their orientation, and it is all the more surprising from the fact that there is no perceptible difference in the young forms of the two sets of figures. Moreover, whole areas of a cleavage surface are covered with pits belonging to a third category, in which the straight edges are the exception and a curved outline the rule (Photograph 7). By an optical illusion, these pits have the appearance of projecting from the general surface after the manner of etch-hills; in so doing, the form of the outline and a pronounced shelly structure, exactly imitating the lines of growth in a molluscan shell, make each pit extremely organic in look. Very often, the shells are greatly elongated in a direction transverse to the cleavage trace (Photograph 7). Only one probable explanation of these two classes of abnormal pits has suggested itself, namely, that the crystals are in a condition of internal tension, which interferes with the workings of the usual molecular cohesions. If this hypothesis be correct, we should expect all transitions between the normal type and the other two abnormal types of figures. Such is the fact, typified in the observed occurrence of pits intermediate to those of the first and second kinds, where the transverse edge is seen to have all directions within the limits set by the enantiomorphous pits (see Photograph 6). Moreover, we might expect on this hypothesis that there should be distorted pits on the cleavages etched with reagents other than HF. Using caustic soda, I obtained normal pits on (110) illustrated in Photograph 9; occasionally, though more rarely than in the case of crystals etched with the acid, the beautifully marked shells were replaced by others elongated transversely.

A possible cause of this distortion by differential tensions is not far to seek. Several carefully cut sections of the mineral showed that it is strikingly zoned, each zone possessing its own tint of color which is

doubtless correlated with a special chemical constitution. It is not difficult to believe that the molecular substance of the crystals may be put into a condition of strain by varying rates of expansion and contraction in the different zones due to temperature changes. Again, there is also possible a massive stress set up in the crystal caused by its contortion in the rock from which it was derived. In this case, we are dealing with a druse-mineral; nevertheless, I have observed that at least two of the individuals are greatly twisted so that the plane of the cleavage is replaced by a curved surface with from 8° to 10° of curvature. Attempts were made to etch this particular crystal on (110), without marked success, although the mineral was strongly attacked; yet the few pits actually obtained seemed to be of the distorted types. May this massive distortion not be the result of differential stress in the zones? *

The Philipstad (cleavage) sub-type of etch-pit is thus analogous to the other sub-types peculiar to hornblendes, but it is *similar* to no one of them. It bears the same relation to the second principal kind of pit observable on this mineral; namely, that on the zone occurring on all the individuals so far examined, just underlying the crystal face (Photographs 4 and 5). Most commonly, they are of the shape illustrated in Photograph 4; that is, while the general habit of the figure is very like that of the Wolfsberg sub-type, there is here a more pronounced blunting of the lower end of the pit by an edge nearly as long as the transverse edge of the upper end. The rarer pits with a sharpened lower end are portrayed in Photograph 5. The photographs show with sufficient clearness the contrast existing between these pits and those characteristic of the inner zones exposed on cleavages. There is never any intermixture of the two kinds; the former is confined to a light colored exterior zone, which appears to be less strongly charged with iron than the inner zones, which are always darker in color. Examination proved that these pits on the outside zone could not be explained as *natural* etchings; they are manifestly the result of an interaction between the acid and the mineral, and probably differing from the figures on the other zones on account of the fact that, while the latter agree in chemical composition fairly closely among themselves, there is a strong chemical peculiarity adhering to the outer zone. That the phenomenon is not confined to the reagent used is evident from the comparative study of

* *Sudden* twisting of crystals does not seem to affect the form of the etch-figures. Thus, I etched a cleavage plate of gypsum which had been bent through an angle of at least 15°. The pits produced had perfectly normal characters, as those recently described by Viola.

Photographs 8 and 9. No. 8 indicates the result of etching (110) (crystal face) with caustic soda. The pits are like those on the inner zones in possessing a shelly structure, but have a different outline (compare Photograph 9).

Before leaving this peculiar hornblende, it should be stated that it stands also in a unique position with respect to the etching properties of the clinopinacoid. I have called the angle $A\,D\,H$ in Figure 8 positive; it varies in value with the different varieties of aluminous amphiboles from 1° to 10°. But, in the analogous pit produced on (010) of the Philipstad hornblende, this angle is always *negative* and averages 2½° in value. The description of the optical and other characters of the mineral is deferred to another occasion. (See following article.)

Etch-Hills on Hornblende, (110).

A digression from the main subject of types of pits of corrosion may be permitted in the form of a short discussion of another result of attack with hydrofluoric acid, namely, etch-hills. The usual effect of dissolving a cleavage piece is, in time, the disappearance of the pits formed at the beginning, and their replacement by these residual bosses. When they are numerous, the mineral has a characteristic mammillated look. Besides the normal bosses left on the removal of the ridges between successive pits, however, there often appear on aluminous amphiboles, when etched rapidly (fresh acid and high temperature), a variable number of remarkable etch-hills which, from their form, can have but little to do with those just mentioned.

As examples, V. 46 furnishes some very striking specimens. I produced these peculiar etch-hills at 3 minutes, at 3½ minutes, at 7 minutes, and also after 12 minutes' suspension in HF gas evolved from a hot (fuming) aqueous solution of that gas. In all four cases, the bosses were on the whole similar in look, and, on account of their perfect development, I shall describe the etch-hills on the cleavage piece last mentioned, as typical of all (Photograph 10). They are bizarre in form and arrangement; in plan, triangles, irregular quadrilaterals of many shapes, trapezoids, pentagons, etc., sometimes in groups of two, three, or a half-dozen, similar to one another in outline, and even showing parallelism between corresponding sides. They are commonly bounded by straight lines that have no definite relation to the hornblende crystal, and are thus in striking contrast to the pits which are oriented in the regular way on the same cleavage face. Occasionally, small groups of the figures have the same form and orientation; thus, three scalene triangles were observed

in one place, with sides mutually parallel. At the same time, other aggregations could be found in which the individuals were bounded by the same number of sides, and with angles sensibly equal, yet the corresponding sides were not parallel and the orientation of the figures was necessarily unlike.

For some time I was without a clue to the meaning of these myriad extraordinary figures, but another of the many valuable suggestions in Becke's writings afforded some light on the problem.* When galenite is etched with hydrochloric acid, the resulting chloride of lead often crystallizes out in areas of local supersaturation of the liquid, particularly in regions where the pits are most numerous. The individual crystals of the chloride may be locally oriented in the same way, and will doubtless, in certain cases, favor a skeleton growth. They serve as a kind of protection to the surface on which they lie; the acid will thus dissolve the intervening parts of the general crystal-surface not so protected, and the substance of the galenite underneath the chloride crystals is left projecting as residual hills on corrosion. The common orientation of these crystals and their skeleton-crystallization (touching the galenite surface only where the regular growth of skeleton crystals would permit) could explain the accordant attitude of certain similarly arranged groups of the bosses.

An analogous explanation is believed to apply to the curious etch-hills on hornblende above noted. The chemical reaction is different, the mechanical cause of differential attack is the same. Instead of hydrochloric acid we have here hydrofluoric acid, and in place of a single resulting compound, the chloride, there are probably several salts of hydrofluoric and fluosilicic acids that are produced during chemical solution of the bisilicate, and in the form of crystals or of skeletal aggregates might serve as the protective caps in the lithographic process. What particular fluorides and silicofluorides would be most likely to play such a role, it is perhaps not impossible to say. From their relative insolubility in warm water, the prisms of fluosilicate of magnesium, the rhombohedrons of the fluosilicate of iron, and the spindle-like crystals of the fluosilicate of calcium, seem to be the most favorable to such action. The more soluble octahedrons of the fluosilicate of sodium and hexagonal prisms of the fluosilicate of potassium might also result in an atmosphere of hydrofluoric acid gas diluted with only a small proportion of vapor of water,

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* Aetzversuche am Bleiglanz, Min. und petrog. Mittheil., 1884–85, Bd. VI. p. 240.

as in the case before us. The tendency of fluosilicate of magnesium to crystallize out in the form of skeletal groupings is noted and figured by Bořicky in his classic work on microchemical methods.* He also describes the actual determination of these various fluosilicates on (010) of an amphibole,† etched with hydrofluosilicic acid.

The Glaucophane Type, (110).

Glaucophane furnishes a new type of pit on (110). It is more elongated than the Hornblende type, is characterized by a more pronounced straightness of edges, and is unique by reason of the parallelism between its longest edge (corresponding to $A\ C$ in Figure 2), and the trace of the cleavage. (See Plate I. Figs. 15 and 16.) It is likewise triangular in outline, possesses three figure-faces on the sides and a migrating bottom face. Gastaldite from the Champ de Praz (P. 59) afforded pits in no respect to be distinguished from those on the Ile de Groix glaucophane. On the other hand, crossite gave figures decidedly differently and more closely allied to the Hornblende type (Plate I. Fig. 17).

The Riebeckite Type, (110).

Figures of corrosion were obtained on riebeckite only with much difficulty, apparently due to its extreme attackability in concentrated acid. They were always excessively small, often with imperfect development; the upper end of the pit was the first to become clearly evident, in the process of maturing. The figure has many points in common with the sub-type noted above on Edenite; it is usually quadrilateral, though sometimes three-sided and analogous to the Wolfsberg sub-type. But it differs from both in its being much *darker* than they in vertically incident light: — the figure-faces are steeper than in the same (110) pit on common hornblendes (Plate I. Figs. 18 and 19).

The Arfvedsonite Type, (110).

Quite an exceptional category of etch-figures is represented in the pits generated on the prism-face of arfvedsonite by the use of hydrofluoric acid. (Plate I. Figs. 21 and 22, and Photograph 11.) Their peculiarities are so salient as to enforce the belief that, in the matter of cohesion on this particular face, arfvedsonite is at least as far removed from the

* Archiv d. naturw. Landesforschung von Böhmen, III. 5, Prague, 1877, Plate I. Fig. 12. Translated by Winchell, 19th Ann. Rep. Minnesota Geological Survey.

† *Op. cit.*, Plate II. Fig. 7.

other amphiboles as it has been proved to be optically. The pit is here a spindle-shaped well defined figure, generally about six times, rarely only four times, as long as it is broad. The spindle is usually ideally perfect, and then the axis can be seen to make an angle with the cleavage cracks of two degrees east of north on (110), two degrees west of north on (1$\bar{1}$0). Many pits show that they are bounded by two curved figure-faces of unequal steepness, and hence of unequal illumination in the microscope. The narrower, darker one lies to the left on (110); it is separated from the other by a narrow light streak that corresponds to the keel of the unsymmetrical canoe. The relations are enantiomorphous on (1$\bar{1}$0). Occasionally, the spindle is blunted with what appears to be an imperfectly formed third figure-face that would represent the upper figure-face of the Hornblende type (Plate I. Fig. 22). The photograph does not give an idea of the exceeding sharpness of these figures, at least as compared with most other amphiboles; there can be no doubt that the type is a distinct one and stands alone.

The figures show the mineral to be holohedral and centrosymmetric and a cleavage plate can be easily oriented in the absence of crystallographic data by observing the position of the adventitious third face, or the direction of the spindle-axes with respect to the obtuse angle of cleavage (110 : 110), and one, say the darker, of the two longitudinal figure-faces of a pit.

Both the symmetry and orientation of arfvedsonite are, however, better made out by the use of figures resulting from exposure to molten caustic soda. A cleavage piece was found after 25 seconds' immersion to be covered with three-sided pits, as depicted in Figure 4. These show once again the radical difference in behavior between arfvedsonite and common hornblende. (Cf. Plate I. Figs. 34 and 35.) It is, furthermore, an interesting case, in that the directions of rapid solution are here transverse to those of rapid solution by the acid, and, secondly, the formation of etch-figures is once again seen to be independent of cleavage.

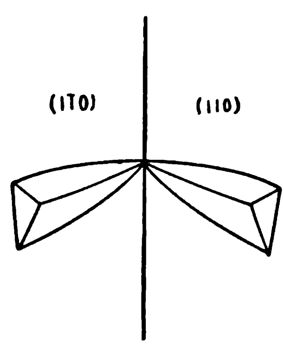

FIGURE 4.

Non-Aluminous Amphiboles, Etch-Figures on (010).

The actinolite of Zillerthal was found to be typical of the whole group of amphiboles not containing a sesquioxide as regards the facts

of etching on the clinopinacoid. Good figures are obtained with ease. (Plate I. Figs. 23*a*, 23*b*, 23*c*.) They are remarkable in belonging to two classes, analogous to those described by Pelikan for pyroxene with the same reagent.* (Photo. 12, cf. Photo. 13.) The pit of the one category is a quadrilateral in outline, with four pyramidal figure-faces and a bottom-face that grows smaller and then disappears as the figure matures and deepens. The other kind of pit is also four-sided in habit, but may possess another pair of figure-faces in addition to the five corresponding to those of the first class. Figures 5 *a* and 5 *b* represent diagrammatically the two kinds matured under normal conditions (water bath, concentrated acid, etc.). The drawings are lettered in order to indicate the elements chosen to fix the shape and orientation of the pits.

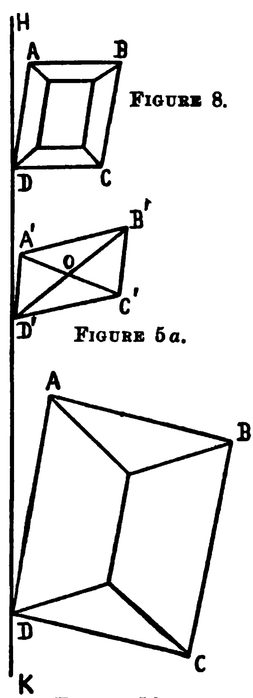

FIGURE 8.

FIGURE 5*a*.

FIGURE 5*b*.

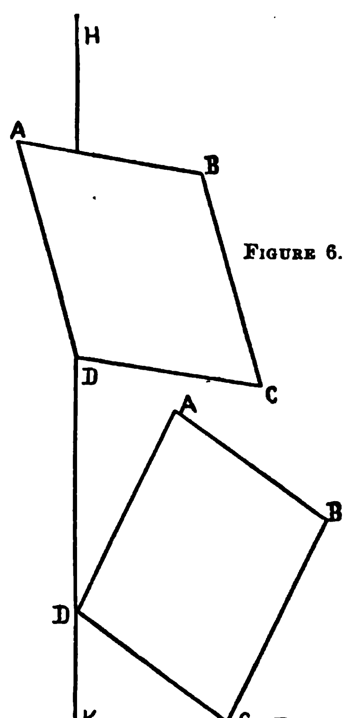

FIGURE 6.

FIGURE 7.

* Ueber den Schichtenbau der Krystalle. Min. und petrog. Mittheil., 1896, Bd. XVI. p. 16.

The smaller pits (Figure 5 *a*) are invariably four-sided and elongated parallel to the side the more oblique to the trace of the cleavage. So extremely minute as to be at times easily overlooked, they are, moreover, inconspicuous on account of their shallowness and the consequent lack of contrast with the rest of the crystal surface; they may hence be called the "light" figures to distinguish them from their darker fellows of the second class to be described. The angle $A' D' H$ was determined at from 3° to 5°, the angle $B' A' D'$ averaged 108°. $A' B'$ and $A' D'$ were measured as under: —

$A' B'$	$A' D'$	Ratio, $A' B' : A' D'$
0.012 mm.	0.012 mm.	3 : 3.
0.011 "	0.009 "	11 : 9.
0.014 "	0.012 "	7 : 6.
0.014 "	0.010 "	7 : 5.

On the average, $A' B' : A' D'$ is about equal to 8 : 5.

Quite different are the pits of the other kind (Figure 5 *b*); they are larger, deeper, and often more numerous. The elongation is, in this case, in the sense of the vertical axis of the crystal. The four-sided figures are, as in the first class, parallelograms in plan, the acute angle here lying, however, in the upper *left* hand corner. It is this corner and the opposite one that are truncated by the accessory pair of figure-faces already mentioned. The angle $A D H$ is 8° instead of 3°–5° in the light figures. The angle $B A D$ varies from 82° to 88°; the curvature of the sides prevents a close determination. The limits of variation in the ratio $A B : A D$ were observed as 1 : 1 (0.04 mm. : 0.04 mm.) and about 2 : 3 (0.032 mm. : 0.048 mm.).

According to the character of the figure-faces (always pyramids) these larger pits can be subdivided into two sub-groups in one of which the faces $A B$ and $C D$ are equally illuminated but darker, i. e. more steeply inclined to (010) than $A D$ and $B C$, also of equal brightness, while in the other group the reverse relation holds. (The figure-faces are here indicated by their corresponding edges of intersection with (010).) Both kinds have figure-faces belonging to the same crystallographic zones, and they are probably allied as are the figure-faces described by Baumhauer on apatite.* He noted — that which is evident from his photographs — that, as the apatite matures (deepens) its faces become steeper and steeper on (0001), ("Verschleppung" of Becke). In one case, I discovered a large pit having $A D$ steeper than $A B$, with the bottom occupied by a

* Resultate der Aetzmethode, p. 48.

second typical pit manifestly of younger generation, but with its *A B* steeper than *A D*. Brauns found on the etched surface of sylvite neighboring pits bounded by figure-faces of different steepness, but he does not seem to have connected the phenomenon with the difference of maturity of the two pits. (See Neues Jahrbuch für Min., etc., 1889, Bd. I. p. 113.)

Either of these types of dark figures may show a keel at the intersection of a pair of figure-faces (Plate I. Fig. 23 *b*).

It was in connection with the study of the pits on (010) of actinolite that I became convinced of the necessity of fixing a standard degree of dilution of the hydrofluoric acid before beginning a series of comparative experiments in etching the amphiboles. The problem could be here more successfully attacked than in the examination of the figures on (110) because of the greater likelihood of being able to observe differences in the shape or arrangement of the systematically straight-edged pits on (010). Six cleavage pieces of Zillerthal actinolite were immersed in HF, either in the form of pure gas or in different states of dilution with water. The procedure and the results are synopsized in the accompanying table, which shows the effects on the angles *A D H* and *B A D* of the dark figures under the different conditions (Figure 6).*

Specimen. No.	Solvent.	Exposure. Minutes.	Angle *ADH*. °	Angle *BAD*. °
(1)	Pure HF (gas)	70	13–14	76
(2)	Com. conc. water solution of HF	$2\frac{1}{2}$	12	75
(3)	75% HF, 25% water	4	2	64
(4)	50% HF, 50% water	15	−2	Acute but indet.
(5)	25% HF, 75% water	25	−11	" "
(6)	10% HF, 90% water	20	−16	" "

No. 1 was etched by hanging it above the surface of some concentrated water solution of the acid, that was very gently heated far below its boiling point, and thus only a small percentage of water vapor could be present during the reaction. The other examples were etched in the ordinary way on a water bath. The percentages of dilution are by volume.

The effect of dilution with water is, then, to produce a rotation of each dark figure about a line perpendicular to the crystal plane. The direction of the rotation is opposite to that of the hands of a watch, its amount (within the limits of these experiments) about 30°. Along

* For Figures 6 and 7 see page 406.

with the rotation, there is a simultaneous distortion of the outline so as to make the angle BAD more and more acute. The latter could not be measured closely in the cases of dilution of 50 per cent or more on account of the poor development of the pits. The longer edge preserved its distinctness much better than did the shorter edge; hence the angle ADH was measurable throughout.

The light figures remained quiescent, neither changing in shape nor orientation, so far as those rather unsatisfactory figures would permit of measurement. In the same manner, I could discover no variations in the pits on the prism-face (110).

Bömer has described other examples of the dependence of the results of etching with hydrofluoric acid on its state of dilution in water. He found the form and attitude of the pits on the base of quartz to alter so much with dilution that, whereas concentrated acid gives figure-faces belonging to the right trigonal pyramids, with very dilute acid they are negative rhombohedrons. Intermediate forms characterize degrees of concentration between these two extremes.* Baumhauer discussed a similar anomalous behavior in the pits on apatite, using hydrochloric acid as the solvent.† There is throughout a close analogy between the pits on (0001) of apatite and those on (010) of actinolite. In both, we have dark figures and two categories of light figures, and, finally, the same tendency to rotate with decreasing concentration of the respective acids in aqueous solution.‡

It is well known that sulphuric acid, when added in small quantities, will in certain cases intensify the solvent power of hydrofluoric acid. I made one or two trials of a basaltic hornblende to see whether in this way the figures of corrosion might be improved. They resulted in partial failure, for, although the pits were a little larger than usual, they lost considerably in definiteness of outline. It then occurred to me to try mixtures of the two acids in various strengths on a more resistant substance, actinolite, primarily to determine what, if any, would be the influence of the sulphuric acid on the etching. The problem was analogous to that just discussed for dilution with water, the procedure was similar, the results just as striking. The table is so like the last as to need no special explanation. (Figure 7.)

* Neues Jahrbuch für Min., etc., 1891, Beil. Bd. VII. p. 535.

† Resultate der Aetzmethode, p. 48.

‡ Becke states that concentration affects the position of the figure-faces in the *etch-zone*. Min. u. petrog. Mittheil., 1883, Bd. V. p. 487.

Specimen. No.	Solvent.	Exposure. Minutes.	Angle *ADH*. °	Angle *BAD*. °
(1)	Pure HF (gas)	70	13–14	76
(2)	Commercial conc. solution	2½	12	75
(3)	95% HF, 5% H_2SO_4	5	11–12	75±
(4)	90% HF, 10% H_2SO_4	3½	19	74–78
(5)	75% HF, 25% H_2SO_4	8	19±	76–78
(6)	50% HF, 50% H_2SO_4	3½ and 8	23	79±
(7)	20% HF, 80% H_2SO_4	3½	26±	Indeterminable.

The mixtures of acids were proportioned by volume.

The table clearly expresses a rotation of the figures with increasing percentages of H_2SO_4 in a right-handed direction, that opposed to the direction of movement in the water-dilution series. At the same time, the angle BAD grows larger, and thus the parallelogram tends more and more towards a rectangular outline. In both respects, the influence of sulphuric acid is in the shaping and the arranging the pits on the clinopinacoid, when etched by means of a mixture of that acid and hydrofluoric acid, the reverse of that of pure water mixed in the same manner with hydrofluoric acid. I am not prepared to offer any explanation of this interesting phenomenon.*

It may be noted that the surface of cleavage (110) exhibits great changes in the etch-figures as the proportion of the sulphuric acid increases. With only 5% of the latter (Plate I. Fig. 24), there is a sensible variation in look from the normal type, and in the 50% solution a strong suggestion of the Wolfsberg figure of common hornblende (Plate I. Figs. 25*a* and 25*b*).

Tremolite and richterite afforded, on the clinopinacoid, etching phenomena identical with those described for actinolite when exposed to concentrated HF; the last mentioned experiments of mixture were not essayed in connection with them.

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* Baumhauer not only showed a rotation of the figures on the basal plane of apatite with increasing dilution of the solvent, hydrochloric acid, but he also established a rotation in the same direction when nitric acid was substituted for the hydrochloric, and a rotation in the *opposite* direction if sulphuric acid be similarly employed. Ref. in Bömer's article, Neues Jahrbuch für Min., 1891, Beil. Bd. VII. p. 538. The accumulation of such facts as these makes it difficult to follow Becke in the hypothesis that his "Hauptaetzflächen" have simple indices, because of greater molecular density in planes having such indices. The molecular density evidently does not change with the solvent. (Min. u. petr. Mitth., 1887, Bd. VII. p. 200).

Etch–Figures on the Clinopinacoid of Aluminous Amphiboles.

The cohesional properties of the plane (010) on any one of the aluminous amphiboles are simpler than those of the same face on actinolite, in that we find the development of only one kind of figure on the former though etched in exactly the same fashion. It corresponds to the light type on the actinolites in several respects, being a parallelogram with the obtuse angle situated in the upper left hand corner and the non-appearance of the adventitious third pair of figure-faces. The equivalence is not complete because of the slight elongation in a vertical sense, and because of a greater obliquity of the figure-faces to the plane (010). (See Fig. 8 on page 406, and Plate I. Fig. 26, and Photograph 14.)

We have seen that the pits on (110) of the hornblendes vary somewhat with the chemical composition; the same is true of the (010) pits. A number of specimens from different localities undoubtedly with considerable, though unknown differences in the proportions of the constituent oxides, were etched, and two of the elements determined in each case, as recorded in the table: —

Specimen.	Exposure.	Angle ADH.	Angle BAD.
	Minutes.	°	°
V. 26	1½	5	95
V. 32	1⅔	4	113
V. 33	1	5	98±
V. 34	1½	7	95
V. 40	1	7	97
V. 42	1	10	100–105
V. 54	2	1	Not determinable.
P. 55	3	4	114

There can be no question, in view of the facts of the foregoing table, that there is a lack of uniformity in the crystallographic zones into which the figure-faces on (010) of hornblendes fall. The differences in outline and orientation are so salient as to impress the eye at once on seeing them in the microscope. Now those hornblendes (V. 26, V. 33, V. 34, V. 40, V. 54) which had the edge AB not far from being sensibly perpendicular to the trace of the cleavage were also characterized by (110) pits of the Wolfsberg sub-type, and those so far studied (V. 32, V. 42, P. 55) that showed important variations from that orientation carried pits more allied to the Kragerö sub-type, if not identical with it. More detailed investigation in the future with carefully analyzed material

may reduce the figures and their individual characters to law, and make the etch-pits of determinative value.

Owing to lack of material, etch-figures were not obtainable on the clinopinacoid of barkevikite, crossite, glaucophane, riebeckite, or arfvedsonite.

Amphibole Etch–Figures on Faces other than (110) and (010).

From the preceding sketch of the pits of corrosion on the prism and clinopinacoid of the aluminous and non-aluminous groups of amphiboles, respectively, it is evident that the general figure-types are modified by variations in the chemical nature of the species. But the prime important modifications are conditioned by the presence in the molecule of alumina, or at least of a sesquioxide. That is, in the one class, we have to do with amphiboles whose molecular constitution is similar, excepting perhaps arfvedsonite; whether it be lime, iron, magnesia, or soda, — any or all of them, — that, together with alumina, compose the complex silicate, the results of etching are always similar.* On the other hand, so soon as the alumina (sesquioxide) molecule disappears, or is present in only very small amounts, there is a radical change in the etch-pits on both faces. This leads to the expectation that other planes will show corresponding change. The few specimens which I have been able to secure confirm that conclusion, and a brief account of the observations thereupon may prove of interest.

Before proceeding directly to them, however, I shall state the negative results characterizing the examination of three other faces (130), (011), and (111); their indefinite etching phenomena did not allow of comparisons by measurement. V. 42 at one minute's exposure exhibited many pits on (130). They were warped triangles, with the upper acute corner pitching into the crystal much after the manner of the analogous hair-like projections described by Tschermak on siderite. (See Baumhauer, Resultate der Aetzmethode, Microgram 20.) The same crystal of V. 42

* Mr. Walker's use of the term "similar" to denote an enantiomorphous relationship between etch-figures seems to me to be inadvisable since it is not needed in that sense, and such a usage deprives us of a convenient designation for figures that are not identical but differ from one another very slightly as in the case of the hornblendes. (American Journal of Science, 1898, Vol. I. p. 181.) "Analogous" might be employed in this connection rather more freely to mean similarity in some one or more features, and would need supplementary statement to indicate wherein the analogy consists.

furnished arrow-headed etch-hills on ($\bar{1}11$). The direction of the arrows was in the sense of, though not parallel to, the b axis inwards. On (011), likewise, the figures of corrosion were etch-hills of triangular shape, in the case of both actinolite and hornblende, but again so ill defined that no certain statement of likeness or unlikeness could be made. V. 16 (actinolite), V. 8 (tremolite), and V. 20 (richterite), at respective exposures of two minutes, two minutes, and one minute, show strong attack on the terminal planes and the development of numerous bosses on (011); the same was true of the hornblendes, V. 33 at two minutes, V. 35 at 1 min., V. 36 at 1½ min., and V. 42 at 1 min. Though characteristic, they do not lend themselves to analysis, and I have been able to accomplish nothing toward comparative detailed study.

Better success was had with the orthopinacoid. Among the aluminous amphiboles, crystals of V. 33, V. 34, V. 35, and V. 42 gave pits at 1½, 1½, 1, and 1 minutes respectively. The result was uniform, — a figure of triangular outline, isosceles, the upper apical angle bisected symmetrically by the plane of symmetry of the crystal. The figure-faces correspond to the edges; two very steep pyramids, a dome at the base and a bottom-face parallel to (100), which diminishes as the pit matures. Occasional figures on V. 42 were notable for the replacement of the pyramids by two pairs of positive and negative pyramids (Plate I. Fig. 28). A much commoner variation is the symmetrical curving of the two lateral edges, probably as an effect of secondary solution as the figure grows older. Simultaneously, the figure tends to grow stouter; thus, a young, light figure of V. 33 was found to have a ratio of altitude to base of 4 : 1, while on the same face a dark matured figure possessed a ratio of 3 : 1. The stoutest figures measured on any hornblende (V. 34), showed a ratio of 3 : 2.

Actinolite pits on (100) display one noticeable difference, and only one, from these last figures; they are more slender (Plate I. Fig. 27). The ratio of altitude to base in the pits of V. 17 (at *CA* 2½ min.) changes from a value of 6 : 1 in the initial figure to a minimum of 3 : 1 in a matured pit. Whether this distinction applies to all the non-aluminous amphiboles or not is a question that needs for its solving more material than I have had the opportunity of studying.

Finally, we have to note the corrosion pits on the dome ($\bar{1}01$).

These are, on the whole, rather difficult to obtain on hornblende by reason of the narrow limits between maximum and minimum times of exposure necessary to bring about their maturing properly. Only three of the species examined afforded good figures, and only one gave those

capable of fairly accurate measurement. The crystals belonged to H. 30, V. 35, and V. 54. The first yielded figures after 30 seconds' boiling in conc. HF, the second on one minute's exposure on the water bath, and the third after two minutes' immersion in a dilute (10%) solution of HF. The plane (Ī01) was in every case strongly affected, and pentagonal pits of corrosion were visible (Fig. 9, and Plate I. Fig. 30).

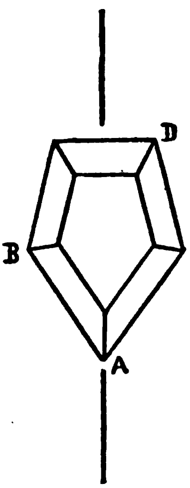

Figure 9.

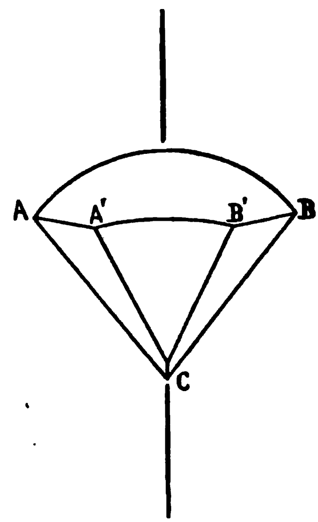

Figure 10.

The measurements on the crystal of V. 35 were as follows: —

$$\angle BAE\ 84°. \quad \angle BCD\ 96°. \quad \angle ABC\ 132°.$$

The outline is symmetrical to the plane of symmetry of the crystal. The acute angle BAE points toward the front (in Tschermak's orientation). Each edge corresponds to a plane figure-face indicated in the drawing, and there is a diminishing bottom-face parallel to (Ī01). The twinned character of V. 54 was clearly manifested in the attitude of the pits on the two adjacent dome-faces intersecting in the twinning-plane (100).

An actinolite (V. 16 at two minutes' exposure) and richterite (V. 20 at one minute) furnished the type of (Ī01) pits characteristic of the non-aluminous amphiboles (Plate I. Fig. 31, and Fig. 10). The figures on the former were extremely sharp, but a photograph could not be pre-

pared on account of the roughness of the general crystal-surface. They are not pentagonal but triangular; two edges, *A C* and *B C* (Fig. 10), meet at an angle of 80° or more, the apex of which points forward on the crystal. The edges *A C* and *B C* are quite straight, and their respective figure-faces are plane. On the other hand, the figure-face *A B B′ A′* is curved and is predominant as a curve even when *A A′ C* and *B B′ C* are not well developed. The bottom plane of the pit is a plane parallel to ($\bar{1}01$) and diminishing in size as the pit matures. *A A′ C* and *B B′ C* are steeper (darker) than *A B B′ A′*, but are of equal obliquity to ($\bar{1}01$), thus agreeing with the other characteristics of the pit in supplying perfect monosymmetry for the figure with respect to (010).

The differences in the etch-pits on the positive unit-dome of the actinolitic species as contrasted with the corresponding pits on hornblendes is striking in face of the fact that we have already seen exemplification of even greater contrasts between the mineral groups in the behavior of the unit prism and the clinopinacoid during the same process of etching.

Isomorphism in the Amphiboles.

Chemical crystallographers are of different opinion regarding the value of etch-figures in determining isomorphism. Arzruni, on the one hand, denies any necessary relationship between them and the fact of isomorphic mixture; * in this he is supported by Baumhauer, who regards the pits on dolomite, calcite, and siderite as not indicating lack of isomorphism, although their orientation on corresponding faces of all three species is widely different.† The opposite view has been strongly maintained by Retgers in his recent and valuable research on the subject.‡ Retgers gives his three criteria of isomorphism as follows: — 1. Mixtures of the constituent salts of an isomorphic series must take place in all proportions. 2. There must be a lack of chemical combination in the mixture: thus diopside ($CaMgSiO_3$) is not a member of the isomorphic series ($CaSiO_3$ and $MgSiO_3$), but an independent body. Likewise manganese augite ($MnSiO_3$) and the manganolime augite ($MnCaSiO_3$) are not isomorphic. 3. Etch-figures produced on the same crystallographic plane of all members of the series will be alike both in shape and symmetry. To support the last statement, he cites a

* Phys. Chemie der Krystalle, 1893, p. 162 *et seq.*

† Resultate der Aetzmethode, p. 37.

‡ Beiträge zur Kenntniss der Isomorphismus. Zeit. für phys. Chemie, 1895, Bd. XVI. p. 36.

number of such isomorphic groups whose etch-figures are known, and in every case there is this similarity among the figures. Thus the experiments of Baumhauer on the double sulphates,* the lime and strontium hyposulphates,† the alums,‡ the phosphate (arsenate) group,§ and the apatite family ; ‖ the studies of Baumhauer and Becke on the carbonates of iron and magnesium ; ¶ those of Wulff on the barium, strontium, and lead nitrates,** and Becke's on spinel and its relatives ; †† all exhibit a marked stability in the form of the etch-pits as the different members of each group are attacked by the same reagent. The earlier objections of Arzruni are considered to have been met by more recent observations of Baumhauer (Res. der Aetzmethode, p. 40). Retgers does not contend that similarity of etch-figures implies isomorphism, as in the two cases of calcite and soda nitrate on the one hand, and the rutile-zircon-cassiterite group, on the other; but regards the converse as a fixed law, "das erhärtete Gesetz," that genuinely isomorphic substances always show, on corresponding surfaces, similar etching phenomena. He further states that "a successful study of isomorphism, without continual controls by means of the methods of etching, is no longer conceivable." ‡‡ At the same time, he remarks that the etch-figures do vary, and that the limits of variation in most groups have not yet been determined; they are, however, as far as known, always narrow limits.

Now, if this contention be valid, the application of the principle to the amphiboles will have important consequences. It will be remembered that tremolite, actinolite, richterite, and astochite, from many different localities and of various chemical composition, gave uniformly the same etch-pits on (110), and, where the material was at hand to determine the point, the same figures on (010), (100), and ($\bar{1}$01). With respect to the same planes, the much greater group of common and basaltic hornblendes, also of very variable composition, agreed among themselves as well as with barkevikite, glaucophane, crossite, and riebeckite ; but each of these two sets of etch-figure types was so strikingly different

* Resultate der Aetzmethode, p. 46.

† Zeit. für Krystallographie, 1877, Bd. I. p. 54.

‡ Ber. der k. bayr. Akad. d. Wissenschaften, 1874, and Res. der Aetzmethode, p. 45.

§ Resultate der Aetzmethode, p. 48.

‖ Ibid., p. 39, and earlier references therein.

¶ Ibid., p. 67.

** Zeit. für Kryst., 1883, Bd. IV. p. 142.

†† Min. und petr. Mitth., 1885, Bd. VII. p. 200.

‡‡ Zeit. für phys. Chemie, 1896, Bd. XX. p. 528.

from the other, that, on etching (110), (010), or ($\bar{1}$01), one could tell with ease whether he be dealing with an amphibole of the first class, devoid of a sesquioxide, or with one of the second, probably aluminous, but possibly one whose iron represented the total content of sesquioxide. The testimony of the etch-pits, then, would be to establish perfect isomorphism in each of the two groups, but to refute the idea that there is isomorphism between the two groups themselves. Whether or not this hypothesis be justified by future investigation, the facts of the case seem to have an important bearing on the theory of Retgers.

Arfvedsonite figures present relationships to the hornblende type, but that species cannot be asserted from them to be in the same isomorphic series with pargasite, for example.

It was thought to be of interest to test further the etching properties of actinolite and hornblende by using caustic alkalies as the solvent instead of hydrofluoric acid. The results were confirmatory of the division just made in the amphiboles. A crystal of Zillerthal actinolite was immersed in molten caustic soda for 15 seconds. A large number of sharply outlined pits were produced on both (110) and (010). Plate I. Figs. 32 and 33 and Fig. 11, are diagrammatic representations of them oriented on their respective planes. Now a cleavage piece of Wolfsberg basaltic hornblende (V. 54) furnished splendid figures on (110) after 35 seconds' exposure in the same reagent, and these were of the varieties shown in Plate I. Figs. 34*a* and 34*b*, and Photograph 16. Another crystal of the Kafveltorp hornblende (V. 42) gave the pits of Plate I. Figs. 35*a*, 35*b*, 35*c*, and Photo. 17, on (110) and pits represented by Figure 12 on (010). Still a third aluminous hornblende (V. 33) from Arendal afforded good figures at 30 seconds, this time practically identical with those of V. 42. Without further analyzing these types, it appears to be a legitimate conclusion that the differing habit of the two may be regarded as significant, not accidental, but indicative of a fundamental difference in the two kinds of substance.

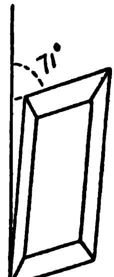

FIGURE 12.

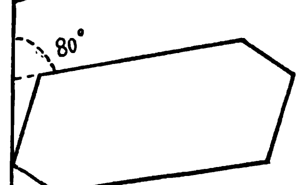

FIGURE 11.

If the tremolite molecule represents one of the fundamental ingredi-

ents in the actinolitic group, the formula of richterite (after Groth, Dana, and Hintze) would have to be recast to show that the latter species is the result of the mixture of $CaMg_3(SiO_3)_4$ with another metasilicate molecule. It would be highly interesting to determine the figures on grunerite ($FeSiO_3$), cummingtonite [$(FeMg)SiO_3$], and dannemorite [$(FeMnMg)SiO_3$], for purposes of similar comparison; many trials with material of the two former from the classic localities failed to produce figures that could be discussed.

The similarity of the riebeckite pits to those on hornblende may go to show that (if it be true non-aluminous riebeckite that was dealt with during the examination) the strong influence of the alumina molecule may be replaced by that of its common associate, sesquioxide of iron.* In any case, the etch-figures in all thirty of the common and basaltic hornblendes, as well as in the glaucophanes and barkevikite, can hardly be explained except as the effect of an interaction of hydrofluoric acid and a common molecule constituted with reference to one or other or both of the two sesquioxides.

In summary, then, if we accept the law that isomorphic mixtures must have similar etch-figures on corresponding crystallographic planes, we have two divisions among the amphiboles, each of which is isomorphic in itself, but not so related to the other group. If this theory be rejected, we have still the facts remaining of an important difference in the structural plan of each division.

Holohedral Character of the Monoclinic Amphiboles.

Throughout the whole suite of specimens which I have studied, the evidence is convincing that the family of amphiboles belongs to the holo-

* Haefcke was so impressed with the importance of alumina in the amphibole molecule that he was led to consider it with the other oxides, to be in combination with orthosilicic acid and thus helps to form salts constitutionally different from the non-aluminous amphiboles, the metasilicates (Inaug. Diss. Göttingen, Berlin, 1890). The masterful influence of alumina is further seen in Wiik's table of extinction angles showing the dependence of the angle of extinction of amphiboles on the percentage of Al_2O_3 present. (Zeit. für Kryst., 1882–83, Bd. VII. p. 79.)

That the *sum* of the sesquioxides as well as the amounts of each should be considered in any comparative study of minerals containing them, is illustrated in an analysis of Doelter's paper on the pyroxenes, in which he traces the influence of alumina and of the sum ($Al_2O_3 + Fe_2O_3 + FeO$) on the optical constant $c : \mathfrak{c}$ of pyroxene (Neues Jahrb. für Min., etc., 1885, Bd. I. p. 43). He finds that FeO alone will not explain the position of $\mathfrak{c}$ with respect to the vertical axis, nor will Al_2O_3 alone nor Fe_2O_3 alone; but he concluded that both the iron oxides added to the

hedral (Groth's "prismatic") class of the monoclinic system. I examined practically all varieties with this point in mind: figures produced with hydrofluoric acid, caustic soda, caustic potash, and bicarbonate of soda, and the attackability of the different faces, all told the same story. Besides the diagrams so often referred to, I shall introduce another to represent etch-pits on (100) of a hornblende (V. 42) acted upon by caustic soda. (Plate I. Fig. 29.)

Comparison with the Pyroxenes.

Many years of comparative study, chemical and physical, have evolved a vast body of evidence to restore something of the early belief in the identity of the pyroxene and amphibole substance,* but it is, after all,

alumina furnished a serial correspondence to the variations in $c : \mathfrak{c}$. If, however, the doubtful case of Mte. Rossi be rejected and it be noted that the extinction $c : \mathfrak{c}$ for the Siderao occurrence was read on a section not quite parallel to (010), it will be seen that the sum ($Al_2O_3 + Fe_2O_3$) gives better results than any of the variables considered by Doelter. Witness the accompanying table: —

Locality.	Extinction Angle (010).	$Al_2O_3+Fe_2O_3$	FeO	Fe_2O_3	Al_2O_3	$FeO+Fe_2O_3+Al_2O_3$
	° ′	%	%	%	%	%
Green Augite, Vesuvius	41 00	8.35	3.16	3.51	4.84	11.51
Greenwood Furnace	42 25	10.14	2.55	5.05	5.09	12.69
Aguas Caldeiras . .	43 35	11.40	4.81	3.51	7.89	16.21
Pedra Molar . . .	45 45	11.85	5.43	6.18	5.67	17.28
S. Vincent	46 45	13.40	5.20	5.25	8.15	18.60
Black Augite, Vesuvius	46 45	14.22	4.09	4.47	9.75	18.31
Garza	47 55	14.61	5.43	4.95	9.66	20.04
Fassaite (Toald. Foja)	47 10	15.11	2.09	5.01	10.10	17.20
Cuglieri	48 00	14.93	5.05	6.32	8.61	19.98
Ribiera das Patas .	51 00	22.13	5.95	7.89	14.24	28.08
Siderao	50 05	22.37	9.14	9.29	13.08	31.51
P. da Cruz	51 50	31.34	2.23	15.37	16.97	34.57

* Tschermak would find in the relative size of molecule the probable ground for difference in those striking external characters, crystalline development, and cleavage. He hypothecates a size for the amphibole molecule just double that of the pyroxene molecule. Cf. Lehrbuch der Mineralogie, 1894, p. 460.

astonishing to observe the very close parallelism which even a cursory study established between the etching properties of the two mineral genera. This is one part of the present investigation which the author regrets to leave in an especially incomplete stage. Thus, it would be of moment to produce etch-figures on that prism of pyroxene (210), which is nearly equivalent to (110) of amphibole, and compare them with those of the last-mentioned face. This has been left undone for lack of material. But even the facts in hand are wonderfully accordant. To simplify matters, I shall enumerate some of the main conclusions we have reached regarding the etch-pits on amphiboles and note the comparisons with pyroxene in connection with each.

1. Actinolitic amphiboles give one class of etch-pits, aluminous amphiboles another, — especially evident on (010), (110), and ($\bar{1}$01). I have been able to find a similar strong contrast between diopside and augite in this respect: they were etched on (010) and (110).

2. Not only is such a double cleavage of the groups possible; there are positive similarities in the respective pits on the pinacoids (010) and (100) of the non-aluminous amphibole actinolite and the non-aluminous pyroxene diopside, and there are positive resemblances characterizing the pits on the same planes of augite and hornblende. The paper of Pelikan,* referred to in detail further on, along with those of Wülfing † and Baumhauer ‡ show clearly that the etching phenomena (outline of figures, number of pits and of figure-faces, orientation of figures, etc.) on (010) of diopside, using hydrofluoric acid, are hardly distinguishable from those on actinolite. (Compare Photographs 12 and 13.) Pelikan § has shown, in addition, that the augites from Vesuvius, Laacher See, Wolfsberg, etc., are characterized by only one sort of pit on the clinopinacoid and thus are in contrast to diopside, and, as we now see, are analogous to hornblende. It must be confessed that no amphibole which I have yet etched has yielded anything like so perfect figures on the orthopinacoid as those readily procurable on the same face of Ala diopside (see Photograph 15). While the general resemblance to the pits on (100) of actinolite is certainly great, I cannot say whether or not the pair of figure-faces at the lower end of the diopside pit is represented in the actinolite pit. (Plate I. Fig. 27, is somewhat hypothetical as to the "primary" figure-faces.) I have not been able

* Min. u. petr. Mitth., 1896, Bd. XVI. p. 1.
† Die Pyroxen Familie, Heidelberg.
‡ Poggen. Annalen, Bd. CLIII. p. 75.
§ *Op. cit.*, p. 21.

to secure etchings of this plane for augite nor of ($\bar{1}01$) for any pyroxene.

3. As was to be expected, the pits on the unit-prism of actinolite and diopside are unlike in outline. I made the experiment of testing the cohesional property of the actinolite substance on a plane making with (010) an angle essentially equal to half the cleavage angle of diopside. A new prism-face was thus ground on a crystal of Zillerthal actinolite, then carefully polished and etched in the usual way, with conc. hydrofluoric acid after two minutes' exposure. The face was found to be covered with etch-hills, the effect of strong attack (much quicker on the artificial face than on any natural face in the prism-zone); but, among them, a few pits which were surprisingly like those on diopside (see Photograph 18), and on aegerine. Further comparison could be made by etching an artificial face on diopside lying 62° 15′ out of the plane of symmetry, and also by using the caustic alkalies in this round of experiment.

4. From the close association of the pyroxenes with our group, it is important to recognise that recently attempts have been made to remove the diopsides from the holohedral class into a hemihedral ("domatische," Groth) class of the monoclinic system. In 1889, G. H. Williams suggested this hypothesis on purely crystallographic grounds, interpreting the imperfect development of the planes about the extremities of the vertical axis of crystals from Orange County, N. Y., and Canaan, Conn., as an evidence of hemihedrism.* In this, he was followed by Dana in the "System" (1892, p. 352). But that the failure of planes about one end of an axis need not mean true structural lack of symmetry is well known, and has lately been exemplified by etch-figures on cuprite that restore it to the holohedral category. Pelikan rightly rejected this argument, but still, on the basis of etching results, he considers it probable that the diopsides are nevertheless hemihedral in Williams's sense.† He was led to this conclusion chiefly by the study of the HF pits on (010). He figures some of these from a Nordmarken specimen which are unsymmetrical in that lines drawn from one side to another through the centre of a pit would not be bisected at that centre; there is, in other words, a lack of that antimetric (dimetric) character necessarily characteristic of (010) if diopside be holohedral. In particular, the asymmetry of the face is supposed to betray itself in the fact that one corner of the rhomboidal figure may be truncated by a fifth figure-face while the oppo-

* Amer. Jour. Science, 1889, Vol. XXXVIII. p. 115. † *Op. cit.*, p. 19.

site corner is not so truncated. But this phenomenon is a familiar one in etching, as pointed out by Becke with reference to siderite and magnesite; it is simply analogous to the unsymmetrical appearance of a crystal, due to the non-development of faces, which, by the known symmetry of the crystal, should appear on it.* Furthermore, Pelikan states that, even in the typical Ala diopside, the regular antimetric pits appear in abundance, and my own observations on another crystal from the same locality (P. 70, Photograph 13) confirm the statement. There is no trace on my well etched specimen of pits that are not antimetric. Secondly, he uses certain figures on the clinopinacoid of Ala diopside as suggestions of hemihedrism because of the curvature of the edges between their respective figure-faces (see his drawing, *Op. cit.*, p. 20). I have not been able to establish the observation by reference to my Ala specimen, and I am inclined to think the curvature must be a consequence of the solution of planes no longer "primary." If secondary solution really exists, (and the numerous experiments of Becke seem to prove it incontestably,) we should expect it to warp the straight edges between primary figure-faces with some such curves as those represented in Pelikan's drawing.

The evidence seems to be perfectly convincing that diopsides as well as augites, amphiboles as well as pyroxenes, are holohedral, and therewith we may close this brief comparative sketch of their etch-figures.

Crystallographic Orientation of the Amphiboles.

The extraordinary resemblance between the amphiboles and pyroxenes in the matter of etch-figures is certainly correlated with likeness in molecular structure, and is an effectual criticism of that mischievous conservatism which has not accepted the arguments of Tschermak, G. H. Williams, and others, in favor of a change in the classic crystallographic orientation of amphibole, introduced by Nordenskiöld. The new differs from the old simply by the rotation of the crystal about the vertical axis

* After these lines had been written, the paper by Baumhauer appeared in the Zeit. für Kryst. (1898, Bd. XXX. p. 97), in which the author stated, as the result of a careful examination of some of Pelikan's original material, that, in his opinion, diopside is holohedral, and that the anomalous pits described by Pelikan are really only imperfectly formed representatives of either of the two types of normal antimetric pits, or are the result of the combination or fusion of these two types (*Op. cit.*, p. 101). On similar grounds, Baumhauer regards Colemanite as monoclinic, although certain etch-pits apparently indicate an asymmetric character for the mineral.

by an angle of 180°. The reasons for altering the old orientation have been so well expressed by Williams that they here need no more than mere mention. (1) The base of pyroxene is an important plane on account of the mineral's well known habit of twinning parallel to that face, and, secondly, on account of the (probably resulting) planes of parting that are so often developed parallel to (001). Amphibole shows both phenomena with reference to the unit dome of the old orientation. (2) Parallel intergrowths of the two minerals are much more intelligible if this unit dome of amphibole, sensibly parallel as it is, to the base of the pyroxene, be really regarded as the base of the amphibole. (3) There can be no doubt that the optical and other properties of the two groups can be more easily compared in the new orientation.

Now, when we remember that the pits on (100) are in both families boat-shaped figures with the bow of the boat headed in opposite directions if amphibole be placed in the old orientation, in the same direction if in the new; that the two kinds of pits respectively characteristic of the clinopinacoid on diopside and actinolite are practically identical in arrangement in the new position advocated; that the cohesional relations of the aluminous amphiboles as regards (010) witness to the same close relationship; and that the analogy of the figures on the two sorts of prismatic cleavage is so well brought out in the greater bluntness of the upper end in each case; — it is undeniable that the physico-chemical facts of corrosion with the acid render it highly expedient to follow Dana in his "System," and Lacroix in "La Minéralogie de la France," in reversing, for purposes of systematic comparison, the orientation so recently, and with so little reason, advocated by Hintze.*

Optical Orientation of an Amphibole Crystal or Cleavage Plate by Means of Etch-Figures.

I cannot subscribe to the opinion of Pelikan,† that the etch-pits on the orthopinacoid and on the clinopinacoid of diopside are valueless for purposes of optical orientation. Whether it be because of different methods of procedure or not, yet I have always found a minimum of difficulty in applying Wülfing's directions for the employment of etch-figures to this end. The same facility of use characterizes the corresponding figures on amphiboles. For their actual application, as well as for that of the pits on (110), the reader is referred to the type

* Handbuch für Mineralogie, p. 1186.

† *Op. cit.*, 1896, p. 12.

diagrams and their accompanying descriptions. In every case, there is no doubt which is the upper end of the cleavage piece, on which the (110) etch-pits can be seen. This study of amphiboles was undertaken primarily to determine the value of etch-figures on cleavage pieces, in order to give a means of orienting those belonging to new varieties which are being so often discovered in allotriomorphic development in crystalline rocks. For this reason, I was especially glad to have access to the many species named in the rather voluminous list of page 379. The conclusion is that, while etch-figures render possible a certain amount of differentiation in the whole family of amphiboles, they yet have so much constancy, so many analogies in outline, as to furnish a reliable means of determining up and down, right and left, in a new variety.

Etch-Figures of Orthorhombic and Triclinic Amphiboles.

There remain two problems which I have set before me for solution by means of etching; one, the crystal system of anthophyllite and gedrite, the other, the comparison of aenigmatite and monoclinic amphiboles in the matter of cohesions on their prismatic cleavage-faces.

Etch-Figures on Anthophyllite and on Gedrite (110).

With no other amphibole did I find so much difficulty in producing and discussing figures of corrosion as on anthophyllite and its near relative, gedrite. By dint of some patience, however, pits were obtained on (110) that fully served the purpose. The relatively great resistance of these minerals to the solvent power of hydrofluoric acid was illustrated in every specimen. Although recognizable pits could be seen on P. 1, P. 2, and P. 3 at 3 minutes, they were often exceedingly small (longest diameter about equal to 0.002 mm.) and the amount of material removed in solution was insignificant. They could not, however, be much enlarged by longer immersion, as shown by a number of trials at various exposures up to 20 minutes. Instead, they became gradually lost in an indefinite confused surface of irregular solution. The best figures were furnished by P. 2 after 2 minutes' exposure (see Plate I. Fig. 36*a* and 36*b*), most of them were very shallow, elliptical in shape, with the longer axes of the ellipses uniformly parallel to the vertical axis of the crystal; they were commonly aggregated along lines of cleavage. As shown in the diagram, other pits were considerably larger, rectangular, sometimes wholly black under vertical incidence of the light (Plate I. Fig. 36*c*), at other times characterized by several visible

figure-faces (Plate I. Fig. 36*d*). These, like the smaller elliptical pits, possessed one plane of symmetry transverse to the trace of the cleavage, and were, of course contrary to expectation, *sensibly* symmetrical to a plane parallel to the cleavage trace. The other three planes of the unit prism showed figures that clearly indicated the holohedral orthorhombic character of anthophyllite. Gedrite (P. 4 at 8 minutes' exposure) afforded precisely similar phenomena to those of anthophyllite.

These observations confirm the optical determinations of orthorhombic symmetry by Des Cloiseaux, and meet the objection thereto by Hintze,* who referred to the possibility that both anthophyllite and gedrite may really be monoclinic, but imitate the optical behavior of an orthorhombic mineral. That these minerals are monoclinic for chemical reasons has more recently been suggested by Retgers: † we have once again an illustration of how etch-figures may come to the help of the chemical theorist.

In passing, it may be noted that the plane of easy parting (010) in hypersthene (P. 69) and bronzite (P. 67 and P. 68) gave with hydrofluoric acid extremely sharp pits with six-sided bisymmetric outline, that betokened orthorhombic symmetry for these minerals, though I could obtain no certain results on etching (110).

Etch-Figures on the Prismatic Cleavages (110) *and* ($1\bar{1}0$) *of Aenigmatite.*

Without destroying the splendid crystals of aenigmatite which Mr. Ussing was good enough to place at my disposal, I was able to etch and orient cleavage pieces of that mineral. The crystals showed (Brögger's orientation) the planes (110), ($1\bar{1}0$), (010), ($\bar{1}\bar{5}1$). The standard conditions of etching were again used, and, after some trouble, both cleavages were finally attacked with successful outcome. Figure 13 and Plate I. Fig. 37*a* will give an idea of the pits. They are triangular in outline, very analogous to the pits on the cleavage of common hornblende, but with a decided peculiarity of orientation. The attitude of the figure-faces shows a greater resistance to attack in a direction parallel to the edge $110 : 1\bar{1}0$ than at right angles to it, a phenomenon we have already noticed in treating of the analogous position of the caustic soda figures on arfvedsonite.‡ Neighboring pits may overlap, and thus the figure-faces

* Handbuch, p. 1180.

† Zeit. für phys. Chemie, 1895, Bd. XVI. p. 618.

‡ Baumhauer observed the independence of etch-figures and cleavage in the case of several species. Poggen. Annalen, 1872, Bd. CXLV. p. 460.

which are nearly parallel to the trace of the second cleavage may run into one another, forming a more or less straight edge in that direction (Plate I. Fig. 37*b*). The small differences in the shape and orientation of the pits on (110) and ($1\bar{1}0$) are such as to form another testimony to the fact expressed by Förstner that cossyrite (aenigmatite) closely approximates a monoclinic habit.* (See Figure 13.)

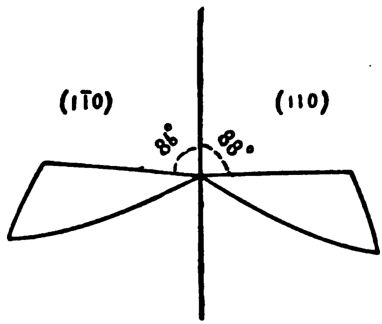

FIGURE 13.

It is possible that the moot question as to whether kölbingite is a distinct species, or (after Brögger) an intergrowth of arfvedsonite and aenigmatite, might be settled by etching cleavage pieces of the mineral.

Zinc-bearing rhodonite (fowlerite, P. 72) is much nearer the monoclinic pyroxenes, as shown by etch-figures, than is aenigmatite like the monoclinic amphiboles. Fowlerite at 45 seconds' exposure gave triangular pits on (110) and ($1\bar{1}0$), which are elongated in the sense of the edge 110 : $1\bar{1}0$, and are strongly suggestive of the pyroxene figures on cleavage plates.

SUMMARY OF CONCLUSIONS.

Reviewing the ground over which we have come, we may make the following brief *résumé* of results: —

(1) It seems to be clear that, for the group of the amphiboles, a special *method* of etching must be adopted, if a comparative study of the etch-figures derived from the different species is to be instituted. A universal solvent must, of course, be used, but its temperature, degree of concentration, and facility of convection at the time of each attack must be attended to if a strict control over the effects of corrosion be possible. It is only by observing this principle, that the measurement of the outlines of pits and their elements of form will lead to the most valued conclusions; and we have seen that measurement, i. e. discussion of the figures by quantitative methods, serves this purpose much more perfectly than does a mere statement of the *kind* of pit or etch-hill to be seen on any given specimen. It has further been shown, with respect to the pits

* Zeit. für Kryst., Bd. V. p. 350.

on the cleavages and on the clinopinacoid of amphibole at least, that the action of hydrofluoric acid is seriously affected by its mixture with pure water and also seriously affected, in the opposite sense, by its mixture with sulphuric acid; the action of pure hydrofluoric acid gas is intermediate to that of both kinds of mixture. Is it not *always* necessary to guard the conditions of attack when etching of crystals by chemical corrosion is to be the means of comparison among the substances represented thus in the crystalline state?

The relatively rapid process of studying etch-figures in vertically incident light can, under the circumstances just outlined, lead to results of importance, not inferior to that attaching to problems where the rather laborious method of determining the exact symbols of figure-faces by means of the goniometer and the Brewster light-figures is necessary.

(2) A scale of optimum exposures for (110) under standard conditions is recorded and the attempt is made to systematize the amphiboles as regards their attackability on the same face. The comparative attackability by hydrofluoric acid of the different faces on certain non-aluminous amphiboles has been determined. It has been found that this property is affected, in large measure, by the physical state of the specimen attacked.

(3) In many instances it has been exemplified that a systematic comparison of etch-figures on different species will be of most service if the observer recognizes the principle that there is a decided change in the etch-pit characteristic of any face, in accordance with the stage it has reached in the process of *maturing* from an initial figure to the often very different figure peculiar to an advanced stage of corrosion. Chiefly for this reason, it has been found difficult, if not impossible, to tell which of the many successive figure-faces composing a given pit on amphibole are the "primary" figure-faces of Becke's definition. It may have been, too, partly for this reason, that I have found it as yet impossible to co-ordinate perfectly the figure-faces and the related directions of easy and difficult solution, so as to construct the "Lösungsoberfläche" characterizing any amphibole.

(4) The curious adventitious etch-hills on hornblende, illustrated in Photograph 12, have led us to suspect that they in no wise represent the true cohesional property of the face considered, but have suggested the hypothesis (following Becke) that they may be due to the unequal protection of the mineral surface by the solid products of the chemical reaction, and that the parts so shielded from attack will project above the general surface after corrosion has further advanced. It would be

interesting to know if other studies of etch-hills will confirm this hypothesis.

(5) A point of considerable theoretical interest is raised by the behavior of the clinopinacoid of actinolite when etched by hydrofluoric acid. It is another of those puzzling cases of the existence, side by side, on the same face, of two quite different kinds of figures, an association for which valid explanation has not yet been vouchsafed.

(6) The amphibole family merits particular notice from the student of etch-figures because it forms a test case for the theory that isomorphic crystalline bodies must have similar etch-figures on corresponding faces. If actinolite and common hornblende, for example, be isomorphous, then their etch-pits must be "similar" in a sense very different from that adopted in the foregoing paper. By our usage, they can only be said to be "analogous." In view of these facts, if this theory of the association of isomorphism and etchings be of universal application, it will be necessary to define more closely than has yet been done by an advocate of the theory, the degree of variability that may occur in the etch-figures of any isomorphous series.

(7) The amphiboles are throughout holohedral.

(8) A further proof of the extraordinary similarity between the pyroxene substance and the amphibole substance is afforded by the study of the pits on crystals showing (010), (100), and (110). This is especially true of the phenomena which can be observed when the clinopinacoid is, in each case, etched with hydrofluoric acid.

(9) It is incontestable that, in spite of their different crystalline development and angles of cleavage, pyroxene and amphibole are so closely and so instructively allied that the standard orientation for both should bring out as conveniently as possible their points of resemblance. Taking etchings as particularly significant of what there be of genuine likeness in the two kinds of substance, there can be no doubt that the orientation proposed by Tschermak should be universally adopted in preference to the older orientation.

(10) It is further possible to make etch-figures on amphibole of practical value by using them as a means of orienting cleavage flakes and other crystal fragments. This use is parallel to that proposed by Wülfing for the pyroxenes.

(11) Lastly, so far as etch-figures may be trusted to show relationships, we have the following results of our survey as to the systematic classification of the amphiboles.

The patent pronounced separation between non-aluminous and alumi-

nous amphiboles, signalized by the two-group division of all our handbooks, is once more confirmed. At the same time, attention has been again called to the overwhelming importance of a sesquioxide, whether iron oxide or alumina, in the mineral.

Glaucophane and gastaldite are the same species, and both isomorphous with hornblende.*

Arfvedsonite appears to hold a more or less independent place in the family of amphiboles.

Barkevikite is more closely related to common hornblende than to arfvedsonite.†

Anthophyllite and gedrite are plainly orthorhombic and holohedral.

Aenigmatite diverges considerably from the amphibole habit, but betrays a tendency toward symmetrical cohesional property, as it does toward crystallographic symmetry.‡

Lastly, it is believed that our present methods of determination of species can be reinforced by the detailed study of mineral groups with respect to etching. The peculiarities of the pits on the cleavages of riebeckite, arfvedsonite, and barkevikite make it easy to say to which of these a given cleavage flake belongs. Similarly, the differentiation of crossite and glaucophane, difficult as it often is by purely optical methods, is ready at hand if the mineral be etched on (110). The striking characteristics of the Philipstad hornblende (V. 101) first became evident in the process of etching cleavage pieces. Its description as a new variety will form the sequel to this paper.

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* Cf. Strüver's statement: "It is probable that glaucophane and gastaldite are isomorphous with amphibole [proper], but it is not yet *proved*." Neues Jahrb. für Min., etc., 1887, Bd. I. p. 217.

† The same opinion is held by Lacroix, chiefly on optical grounds (Minéralogie de la France, Tom. I. p. 561); the opposite opinion by Brögger (Zeit. für Kryst., Bd. XVI. p. 414), followed by Dana (System, p. 403), and Hintze (Handbuch, p. 1256).

‡ See Brögger, *op. cit.*, p. 424.

PLATE I.

Fig.

1. Initial form of pit, Actinolite type (110), HF. × 300.
2. Mature pit of the Actinolite type (110), HF. × 300.
3. Another form of the mature pit of the Actinolite type (110), HF. × 300.
4. A rather exceptional variant on the normal Actinolite type (110), distinguished by a well defined fourth figure-face at the lower end, HF. × 300.
5. Initial form of the Wolfsberg sub-type (110), HF. × 1800.
6. The Wolfsberg sub-type (110), HF. × 300.
7. Compound stepped etch-pit of the Wolfsberg sub-type (110), HF. × 300.
8. Exceptional pit of the Wolfsberg sub-type, showing a fourth figure-face at the lower end (110), HF. × 300.
9. Immature pit of the Kragerö sub-type (110), HF. × 300.
10. Matured pit of the Kragerö sub-type (110), HF. × 300.
11. Another form of the last on another Hornblende variety, showing the common occurrence of a fourth figure-face at the lower end of the pit. × 300.
12. An exceptional pit found on (110), along with the pits of Figure 11. × 300.
13. The Edenville sub-type (110), HF. × 600.
14. Another form of the last, where the individual figure-faces can no longer be distinguished. × 600.

15 and 16. Two forms of the Glaucophane type (110), HF. × 600.

17. The Crossite type (110), HF. × 1000.

18 and 19. Two forms of the Riebeckite type (110), HF. × 1000.

20. The type of pit on Barkevikite (110), HF. × 300.

21 and 22. Two forms of the pits on Arfvedsonite (110), HF. × 175.

23*a*, 23*b*, 23*c*. Pits on (010) of Actinolite, HF. 23*a* is the "light" etch-pit, the other two the "dark" pits simultaneously occurring with the first, HF. × 300.

24. The modification of the normal pit on Actinolite (110) by the admixture of 5% sulphuric acid to the commercial hydrofluoric acid generally used. × 300.

25*a* and 25*b*. The same as the last, except that the admixture is here 50% of sulphuric acid. × 300.

26. The type of pits on (010) of common and basaltic (aluminous) Hornblendes, HF. × 300.
27. A pit on (100) of Actinolite (non-aluminous amphibole), HF. × 300.
28. A pit on (100) of basaltic Hornblende (aluminous), HF. × 300.
29. Caustic soda pit on (100) of basaltic Hornblende. × 300.
30. Pit on ($\bar{1}01$) of basaltic Hornblende, HF. × 600.
31. Pit on ($\bar{1}01$) of Actinolite and other non-aluminous amphiboles, HF. × 300.

32 and 33. Caustic soda pits on Actinolite (110). × 1200.

34*a* and 34*b*. Caustic soda pits on basaltic Hornblende (110). × 300.

35*a*, 35*b*, and 35*c*. Caustic soda pits on the Kafveltorp Hornblende (110). × 600.

36*a*, 36*b*, 36*c*, and 36*d*. The various types of pits produced on Anthophyllite and Gedrite, (110), HF. × 3000.

37*a* and 37*b*. Pits on Aenigmatite (110), HF. × 3000.

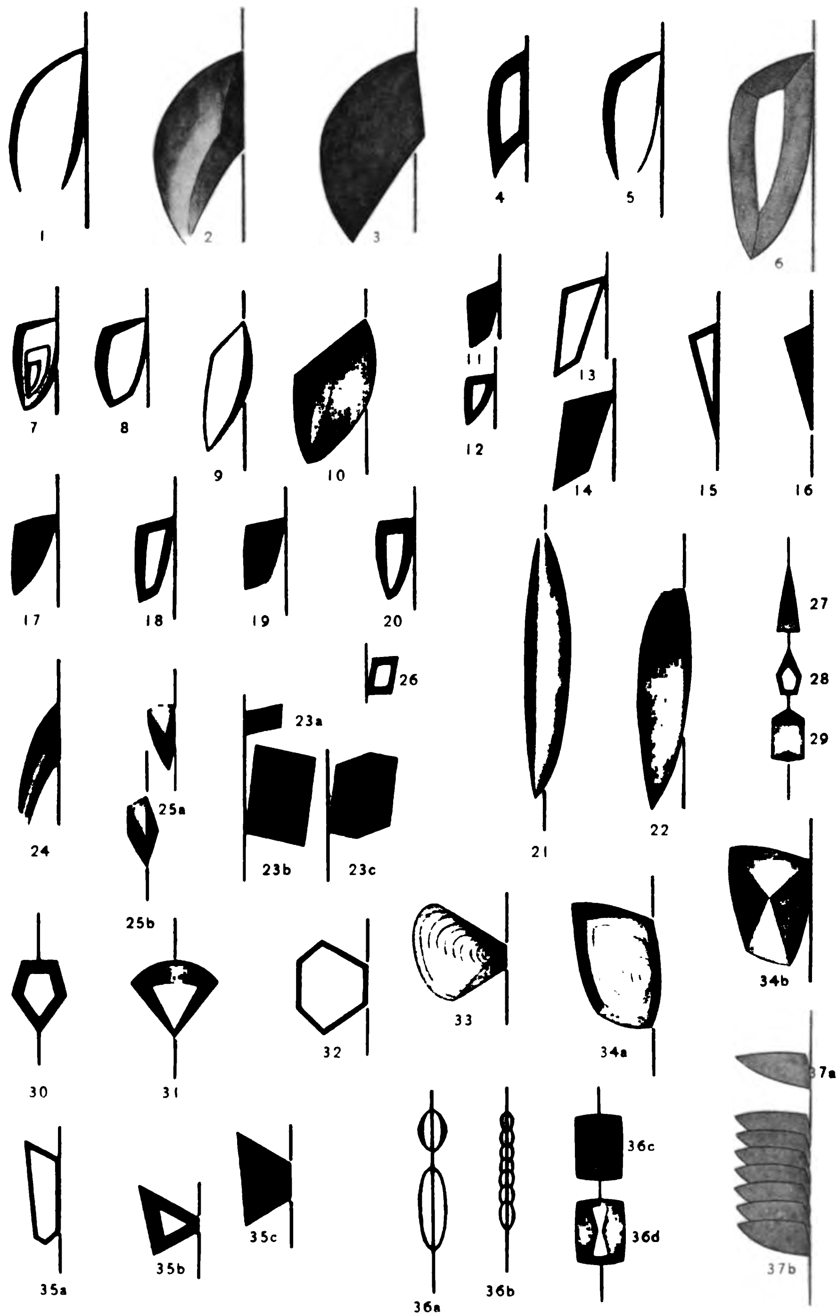

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PLATE II.

DESCRIPTION OF THE MICROPHOTOGRAPHS.

Etch-figures are illustrated as follows: —

No. 1. Actinolite type on (110), Zillerthal Actinolite, HF. × 88.

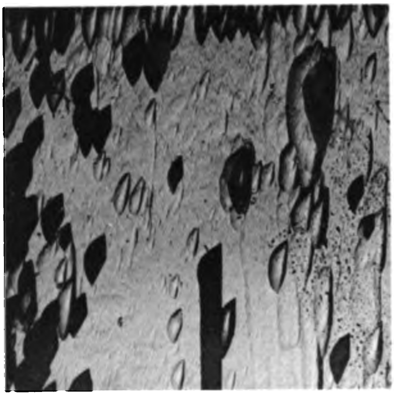
No. 2. Kragerö sub-type on (110), Kragerö Hornblende, HF. × 78.

No. 3. The same on another variety, Kafveltorp Hornblende. × 78.

No. 4. Philipstad sub-type on (110), (crystal face = outer zone), showing pits with blunted lower end, Philipstad Hornblende, HF. × 225.

No. 5. The same on another crystal, showing pits characterized by a sharpening of the lower end. × 95.

No. 6. Philipstad sub-type on (110), (one form on the cleavage surface of the inner zones,) Philipstad Hornblende, HF. × 225.



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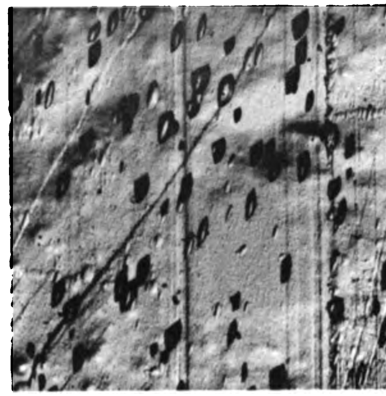

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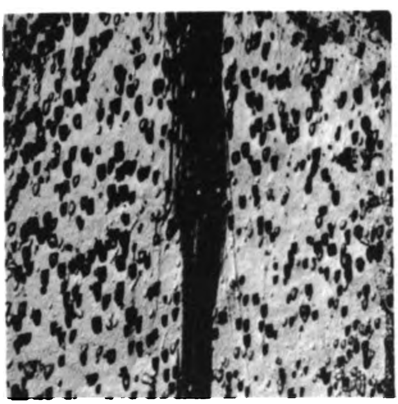

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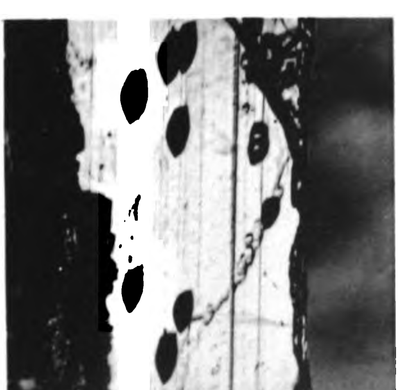

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PLATE III.

DESCRIPTION OF THE MICROPHOTOGRAPHS.

Etch-figures are illustrated as follows : —

No. 7. The same as No. 6 on another crystal, showing the common distortion of the pits, HF. × 78.

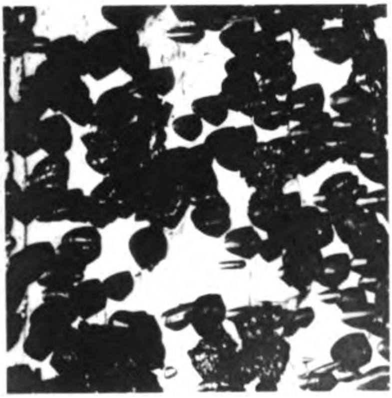
No. 8. Caustic soda pits on Philipstad Hornblende (110), (crystal face). × 225.

No. 9. Caustic soda pits on Philipstad Hornblende (110), (cleavage, inner zones). × 225.

No. 10. Etch-hills on (110), basaltic Hornblende from Mayenegg (HF gas). × 71.

No. 11. Pits on (110), Arfvedsonite from Kangerdluarsuk, HF. × 78.

No. 12. Pits on (010), Zillerthal Actinolite, HF. × 78.



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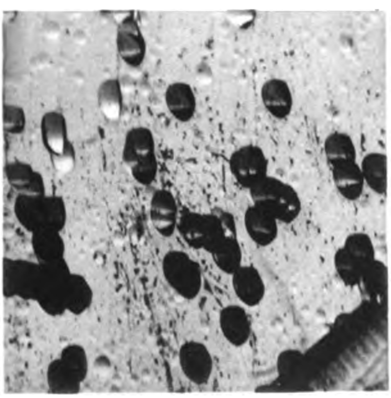

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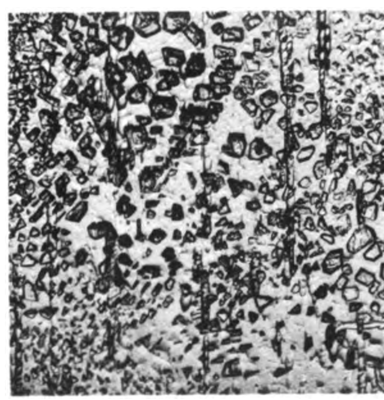

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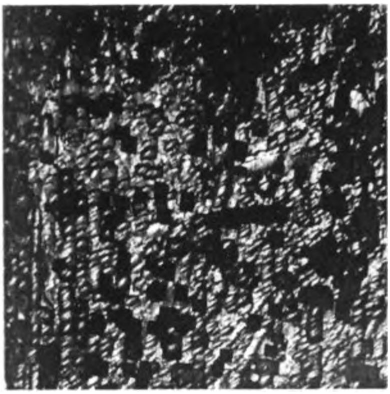
THE HELIOTYPE PRINTING CO., BOSTON

PLATE IV.

DESCRIPTION OF THE MICROPHOTOGRAPHS.

Etch-figures are illustrated as follows: —

No. 13. Pits on (010), Ala Diopside, HF. × 78.
No. 14. Pits on (010), basaltic Hornblende from Kafveltorp, HF. × 78.
No. 15. Pits on (100), Diopside from Ala, HF. × 78.
No. 16. Caustic soda pits on (110), Wolfsberg basaltic Hornblende. × 78.
No. 17. Caustic soda pits on (110), basaltic Hornblende from Kafveltorp. × 225.
No. 18. Pits on (110), Diopside from Ala, HF. × 78.



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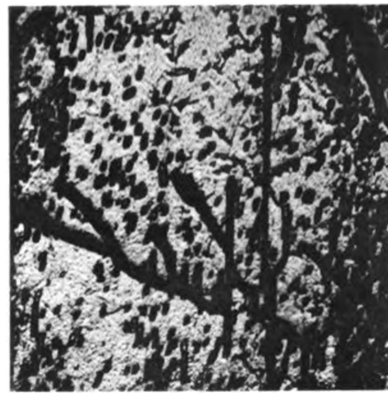

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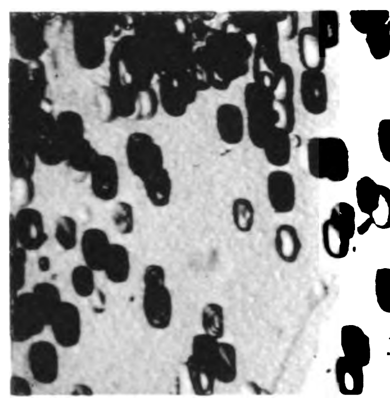

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THE HELIOTYPE PRINTING CO., BOSTON

Proceedings of the American Academy of Arts and Sciences.

VOL. XXXIV. No. 16. — MARCH, 1899.

V.—CONTRIBUTIONS FROM THE HARVARD MINERALOGICAL MUSEUM.

ON A NEW VARIETY OF HORNBLENDE.

BY R. A. DALY.

ON A NEW VARIETY OF HORNBLENDE.

By R. A. Daly.

Presented by J. E. Wolff, February 8, 1899. Received February 11, 1899.

The abnormal etching characters of the Philipstad hornblende referred to in the foregoing paper have suggested further study of the mineral; the description of its other properties shows that it should be regarded as an independent member of the amphibole group.

It is a variety given me for study by Professor Berwerth of the Royal Museum in Vienna. It is catalogued in that collection as "A. o. 458, Philipstad, Sweden." In addition to the original cleavage pieces for etching purposes, Professor Berwerth has been kind enough to turn over to me several fine crystals from the parent druse and enough extra material to permit of chemical analysis. To him, in thus abundantly supplying me with the mineral, my best thanks are due.

The crystals stand upon a compact mass of the same hornblende. The usual planes (110), (010), (100), (130), (011), (Tschermak's orientation), with normal interfacial angles, are well developed. The adjoining table shows the close correspondence of the observed angles with the calculated angles (cf. Lacroix, Minéralogie de la France): —

	Observed.	Calculated.
110 : 130	150° 9′	150° 6′
010 : 130	147° 23′	147° 29′
110 : $1\bar{1}0$ (faces)	124° 11′–124° 17′	124° 11
" " (cleavages)	124° 27′	
110 : 010	117° 50′	117° 54′
110 : 011	68° 33′	68° 46′
011 : $0\bar{1}1$	149° 12′	149° 11′

The unit prism is usually striated, owing to the presence of vicinal planes.

The reflexes in the goniometer from the planes of the vertical zone were often considerably displaced. This is probably due to the warping of the crystals. In several of the latter, it is possible to see with the

naked eye a marked flexure and even twisting of the prism-faces. I consider that the curious distortion of the etch-figures on (110) is due to the warping and consequent molecular strain.*

Several of the crystals are twinned parallel to (100).

The different etching behavior of the crystal-face and of the surface of cleavage has been explained as due to the zonal structure which is a prominent characteristic of the mineral. Six oriented sections and numerous cleavage pieces display the structure: it is illustrated in Figures 1, 2, and 3.

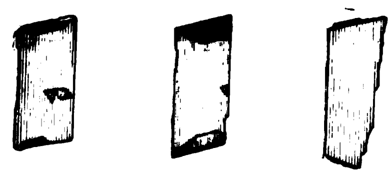

FIGURE 1. FIGURE 2. FIGURE 3.

FIGURES 1 AND 2. — Two sections parallel to (010) of the same doubly terminated crystal, showing zonal structure. In Figure 1 three zones, in Figure 2 four zones, are indicated. The zone of deepest tint is the most closely shaded, that of the lightest tint is left unshaded. The lines of shading run parallel to the cleavage trace. The trace of the edge 010 : 011 slopes downward from right to left.

FIGURE 3. — A section parallel to (110), showing three zones represented as in Figures 1 and 2. The extinction of the lightest zone is 17°, that of the intermediate zone is 19°, and that of the darkest zone is 22° 30′.

That this structure is rare in the amphiboles is clear from the recent statement by Becke in his essay on the zonal structure of crystals in the eruptive rocks.† Brögger describes one case in connection with his catophorite series. He notes the fact that sometimes the core of a crystal may consist of catophorite and the outer zone of arfvedsonite.‡ Tschermak long ago noted another example in a Vesuvius hornblende.§ Palache has figured the structure in crossite. ||

The diagrams show that the bulk of each crystal is composed of pretty uniform substance, in which a darker colored phase of the mineral may be apparent, either without definite arrangement with respect to the former or in the form of true hour-glass intergrowth with it. In the

* See These Proceedings, Vol. XXXIV. page 400.

† Min. und petrog. Mittheilungen, 1898, Bd. XVII. p. 101.

‡ Die Gesteine der Grorudit-Tinguait-Serie, pp. 27 *et seq.*

§ Min. und petrog. Mittheilungen, 1871, Heft I. p. 40.

|| Bulletin, Department of Geology, Univ. of California, Vol. I. p. 187.

latter case, the darker areas of the section generally occur at the ends of the crystal, representing a late stage of growth, and are, with the rest of the crystal, commonly covered with a thin mantle of still a third kind of substance considerably lighter in tone than either of the other two.

Accurate sections cut in the appropriate directions by M. Werlein of Paris enabled me to determine the chief optical properties of the hornblende. The optical plane is parallel to the plane of symmetry. The axis of least elasticity lies in the obtuse angle β (Tschermak's orientation), making an angle of 15° 9′ with the vertical axis using yellow light or 15° 5′ using white light. The mineral is negative. In oil with an index of refraction of 1.609, I found the optical angle (2 H) to be 53° 24′; in another oil with an index of refraction of 1.5011, I determined 2 H to be 57° 24′. The hyperbolas were not well defined, and, on account of strong absorption, the readings had to be made in the brightest white light procurable.

Owing to the extreme ease with which the mineral cleaves, it was found impossible to cut oriented prisms for the purpose of finding the indices of refraction; nor was any other method feasible under the circumstances. The true optical angle cannot then be found from 2 H, since the mean index of refraction is not known. It may, however, be considered that this index lies within the limits of 1.622 (tremolite) and 1.725 (hornblende, a high value). The first reading for 2 H (53° 24′) would give for $\mathfrak{b} = 1.622$, $2\ V = 52° 56'$, and for $\mathfrak{b} = 1.725$, $2\ V = 49° 42'$. The second reading (57° 24′) would give for the same values of $\mathfrak{b}$, $2\ V = 52° 46'$ and 49° 24′. The closeness of the agreement in the respective calculated values of 2 V is rather fortuitous. The optical angle for this section is, then, within a degree or so of 50°.

The double refraction seems to be low. The dispersion is weak ($\rho < v$).

On (110) the extinction varies with the zones, increasing with the depth of tint. One dark zone gave in white light an average reading of 20° 53′; other lighter zones afforded extinction angles as low as 17°. The total range, so far as observed, lies between 22° 30′ and 17°. This can only mean that the optical angle for the different zones varies and must have values between 42° and 60°. (See Figure 3.)

The pleochroism is very strong in characteristic colors: —

$\mathfrak{a}$ = light brownish green.
$\mathfrak{b}$ = dark yellow green.
$\mathfrak{c}$ = dark blue green.

$$\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$$

This scheme of color and absorption applies to all the zones, the colors being simply modified in intensity.

The specific gravity was determined in methyl iodide solution at 16° C. The average for two unaltered crystals is 3.275. An outer light-colored zone gave 3.195, and an inner darker zone 3.230. The difference between the last two was too small to permit of the separation of the light and dark zones. I doubt that the lightest zone is more than one per cent of the whole. There are no important inclusions in the mineral.

M. Pisani of Paris made an analysis of the hornblende; it resulted as follows:—

SiO_2	45.20
TiO_2	0.84
Al_2O_3	7.34
Fe_2O_3	7.55
FeO	15.80
MnO	1.52
CaO	12.30
MgO	8.40
Na_2O	0.80
K_2O	0.37
Loss on ignition	0.70
	100.82

The analysis does not lend itself to calculation in a satisfactory way. There is considerable divergence in the proportions of the oxides from an old analysis by Rammelsberg of a Philipstad hornblende with a specific gravity suggestively close to that of our hornblende.*

It will be seen that the most noteworthy feature of the analysis is the high percentage of ferrous iron, a fact which correlates the mineral with hastingsite, which also has an unusually great proportion of this oxide, as well as an extraordinarily small optical angle.†

That a high content of ferrous iron (plus MnO) always means a correspondingly small optical angle cannot be asserted; pargasite affords a case sufficiently clear to invalidate any such claim. Yet it does seem that there is some intimate relationship between the amount of the oxide and the optical angle. The analogy of another group of allied silicates is in striking corroboration of this conclusion. Thus Hintze ‡ gives a table

* See Hintze, Handbuch der Mineralogie, 1894, p. 1223.

† Cf. Adams, Canadian Record of Science, 1896, Vol. VII. p. 77.

‡ Handbuch, p. 964.

of fourteen chemical and optical analyses of enstatite wherein the optical angle in oil continuously decreases from 133° 8′ (red light) to 59° 20′ (green light) while the percentage of (FeO plus MnO) simultaneously increases from 2.76% to 33.6%.

This hornblende is thus unique among the species yet described in that it possesses the combination of properties including an unusually small optical angle, an unusual pleochroism and absorption scheme, a well developed zonal structure, and quite anomalous etch-figures with hydrofluoric acid on the prism (110) and on the clinopinacoid.

For convenience of reference, this variety of amphibole may be called philipstadite, from the name of the locality whence it was derived.

Proceedings of the American Academy of Arts and Sciences.

VOL. XXXIV. NO. 17. — MARCH, 1899.

THE ORTHOPTERAN GENUS SCHISTOCERCA.

BY SAMUEL H. SCUDDER.

THE ORTHOPTERAN GENUS SCHISTOCERCA.

By Samuel H. Scudder.

Received February 20, 1899. Presented March 8, 1899.

Schistocerca belongs to the Acridii, the typical group of Acridiinæ, in which the fastigium is deflexed and passes insensibly into the frontal costa, lateral carinæ are wanting on the pronotum, the mesosternal lobes are longer than broad and usually produced and strongly acutangulate posteriorly on the inner side, the hind tibiæ have smooth margins with numerous spines regularly disposed on both sides, but with no apical spine on the outer margin, and the second tarsal joint is only half as long as the first.

There is but one other genus in the group, Acridium, from which Schistocerca was separated by Stål in 1873, on account of the apically broader anal cerci of the male and the apically fissate subgenital plate of the same sex. In doing this he also separated the Old World species of Acridii from those of the New World, for Acridium does not occur in America and Schistocerca is found only in the New World, except for a single species, which occurs both in South America and in Africa, but which has also been found in such circumstances in mid-ocean as to render it in the highest degree probable that Africa was originally colonized from America.

Schistocerca is therefore normally an American genus. Like Acridium it is composed of large species with a wing expanse usually reaching nearly or quite a decimeter, though it contains more species of a moderate size than does Acridium, and some much smaller than any Acridium known to me. Two at least of the larger forms, including the species common to the two worlds, are known to be both migratory and very destructive; but the greater number appear to do less harm than their large size would lead us to expect. The species of Acridium are mostly confined to Africa, southern Asia, and Australia, and many species are apparently still undescribed.

A considerable number of species of Schistocerca have been described from America, but many have received more than one name, even since

Stål first brought together the synonymy of the species known to him, in his Recensio Orthopterorum; and a number of described forms are still indeterminable with the considerable material I have brought together for their study. Especially is this true of Walker's species, his genera Acridium and Cyrtacanthacris being heterogeneous assemblages of species of many genera, and usually quite impossible of determination apart from the specimens themselves in the British Museum.

Unfortunately, a not inconsiderable part of the material on which the species are here separated is not so good as one could wish, being specimens dried after previous immersion in spirits, — a favorite mode of collecting these bulky Acridians, but one which dulls the coloring and often exaggerates the salient parts of the structure of the head and pronotum. I have therefore relied as little as possible on mere color, which nevertheless plays a very important part in the distinction of species in this genus. It takes a longer immersion to destroy the markings, but these also are sometimes lost. On this account I have been obliged to discard a small part of my material, which seemed to indicate additional species coming from localities, from which one rarely obtains specimens.

Of the forty-four species here tabulated, eleven are known from the United States, twenty-three from Mexico or Central America, six from the West Indies, and twenty from South America (including the Galapagos), besides one of which the provenance is unknown, but which probably belongs to South America.

I am indebted to my friends, Messrs. S. Henshaw, A. P. Morse, and L. Bruner, for loans from their collections, and have had all the material from Central and South America in the Museum of Comparative Zoölogy for study. The main portion of my material is found in my own collection. Only the new forms are described, but the following table will enable one to determine any of the species I have seen, new or old.

TABLE OF THE SPECIES OF SCHISTOCERCA.

a^1. Antennæ of male (those of female always relatively shorter) nearly or quite one third, often one half, longer than head and pronotum together.

b^1. Pronotum rectangulate behind, or in the female faintly obtusangulate, the angle narrowly or very narrowly rounded.

c^1. Tegmina distinctly maculate or if occasionally feebly and obscurely maculate, then the pronotum is unstriped above; lateral lobes rarely with any markings, and when present rarely separated obliquely.

d^1. Pronotum with no, or at most very obscure, dorsal stripe, the lateral lobes at most clouded with fuscous.

e^1. Pronotum not or scarcely tectiform; eyes normal.

f^1. Relatively small and slender; prozona as long as metazona; greatest dorsal width of metazona not exceeding width at eyes . . 1. *gracilis.*

f^2. Relatively stout and large; prozona shorter than metazona; greatest dorsal width of metazona exceeding width at eyes.

g^1. Wings flavo-fuliginous . . . . 2. *aurantia.*

g^2. Wings hyaline with fuscous veins.

h^1. Maculation of tegmina delicate, obscure, in the distal half substrigate . . . . 3. *carinata.*

h^2. Maculation of tegmina coarse, distinct.

i^1. Wings more or less distinctly infumate; prosternal spine erect.

j^1. Fusco-testaceous; hind femora with hoary outer face; hind tibiæ purple . . . . 4. *columbina.*

j^2. Olivaceo-testaceous; hind femora and tibiæ flavo-olivaceous . . . . 5. *crocotaria.*

i^2. Wings hyaline; prosternal spine retrorse . . 6. *interrita.*

e^2. Pronotum distinctly tectiform; eyes more oblong than usual.
7. *camerata.*

d^2. Pronotum with median dorsal stripe and diversified lateral lobes.

e^1. Dorsal stripe of pronotum of equal width throughout; lateral lobes longitudinally banded, the bands not or scarcely oblique.

f^1. Prosternal spine slender; wings more or less infumate; hind femora without fasciation.

g^1. Males with no distinct dorsal stripe; maculation of tegmina distinct; wings distinctly flavo-infumate throughout . . . 8. *mellea.*

g^2. Males with a conspicuous pale dorsal stripe on head and pronotum; maculation of tegmina often obscure; wings very feebly infumate at most . . . . 9. *zapoteca.*

f^2. Prosternal spine stout; wings hyaline or nearly hyaline; hind femora obscurely fasciate.

g^1. Pronotum very coarsely carinate, the position of the lateral carinæ unmarked; tegmina densely maculate . . . . 10. *vaga.*

g^2. Pronotum finely carinate, the position of the lateral carinæ marked anteriorly with fuscous; tegmina sparsely maculate. 11. *simulatrix.*

e^2. Dorsal stripe of pronotum narrowing from in front posteriorly.

f^1. Lateral lobes of pronotum mottled and longitudinally variegated with fuscous, the lower anterior margin not distinct from the rest; costal area of tegmina with no light streak . . . . . . 12. *pyramidata.*

f^2. Lateral lobes of pronotum with a strongly oblique anterior and inferior light patch, edged with fuscous; costal area of tegmina marked with a pallid streak . . . . 13. *desiliens.*

c^2. Tegmina immaculate, or if rarely feebly and obscurely maculate, then the pronotum is marked with a dorsal stripe, narrowing posteriorly; lateral lobes of pronotum often marked below with dull yellow, separated very obliquely from the darker parts above.

d^1. Lateral lobes of pronotum with a very obliquely delimited inferior clay yellow patch, often obscure in the female.

e^1. Median stripe of pronotum generally narrowing from in front backward; wings more or less and simply infumate.

f^1. Antennæ of male about one half as long again as head and pronotum together; tegmina immaculate, or feebly and obscurely maculate; wings feebly infumate . . . . 14. *flavofasciata.*

f^2. Antennæ of male not more than one third as long again as head and pronotum together; tegmina immaculate; wings distinctly infumate . . . . 15. *infumata.*

e^2. Median stripe of pronotum broad and equal throughout; wings flavo-infumate . . . . 16. *æqualis.*

d^2. Lateral lobes of pronotum without markings . . . . 17. *maya.*

b^2. Pronotum distinctly obtusangulate behind, even in the male, the angle generally rather broadly and obtusely rounded at apex.

c^1. Pronotum never tectate, or at most but very feebly; tegmina more or less distinctly, generally distinctly, maculate throughout (or, if without maculation, the head, pronotum, and closed tegmina have no light colored dorsal stripe); wings generally hyaline, occasionally lutescent basally or even throughout, the veins fuscous or ferruginous, rarely luteous; lateral lobes of pronotum often marked conspicuously with longitudinal fuscous stripes on a lighter ground, but often unmarked.

d^1. Pronotum so broadly and strongly rounded behind as to be rotundate, rather than obtusangulate; prosternal spine somewhat retrorse.

18. *australis.*

d^2. Pronotum distinctly angulate behind, the angle more or less but not greatly rounded, at least in the male; in the female it is sometimes rather broadly rounded.

e^1. Pronotum never tectate, generally distinctly striped on the lateral lobes.

f^1. Hind femora not transversely fasciate.

g^1. Prosternal spine erect or suberect, straight or almost straight; lateral lobes of pronotum not or feebly marked, and then irregularly blotched.

h^1. Dorsal stripe of pronotum obsolete; maculations of distal half of tegmina slight and scattered, or if at all regular it is to form numerous narrow one- or two-celled transverse broken stripes.

19. *gulosa.*

h^2. Dorsal stripe of pronotum moderately distinct; maculations of distal half of tegmina massed in several rather broad oblique bands . . . . 20. *bogotensis.*

g^2. Prosternal spine distinctly curved and retrorse; lateral lobes of pronotum distinctly banded longitudinally.

h^1. Pronotum griseous, slenderly strigate with fuscous; wings nearly hyaline . . . . 21. *inscripta.*

h^2. Pronotum with a broad median light dorsal stripe between fuscous bands; wings flavo-infumate . . . . 22. *idonea.*

f^2. Hind femora distinctly trifasciate.

g^1. Pronotum with no dorsal stripe; tegmina distinctly maculate throughout; interspace between eyes distinctly narrower than narrowest part of frontal costa . . . . 23. *literosa.*

g^2. Pronotum with a median dorsal stripe; tegmina feebly or not maculate, especially in the distal half; interspace between eyes not or scarcely narrower than narrowest part of frontal costa.

24. *melanocera.*

e^2. Pronotum feebly tectate, at least in the female, not striped or very obscurely striped on lateral lobes.

f^1. Metazona rugulose as well as punctate; maculations of tegmina when present quadrate or rounded; male cerci of subequal breadth, tapering only in distal half; subgenital plate of moderate length, apically with a rather shallow V-shaped emargination.

25. *rubiginosa.*

f^2. Metazona punctate but scarcely rugulose; maculations of tegmina distinctly elongate; male cerci tapering throughout so as to be at apex only two thirds as broad as at base; subgenital plate long and slender, apically deeply fissate . . . . 26. *sonorensis.*

c^2. Pronotum generally more or less tectate; tegmina immaculate, or at most marked linearly with fuscous or yellow on lower half (or if, rarely, distinctly maculate, then the head, pronotum, and closed tegmina are distinctly marked by a light colored dorsal stripe); wings generally lutescent with luteous veins; lateral lobes of pronotum very rarely with conspicuous and definite markings, generally clear or irregularly mottled.

d^1. Pronotum with a distinct percurrent median light colored stripe.

e^1. Lateral lobes of prozona immaculate, or with feeble light colored stripe at or above the middle.

f^1. Dorsum of metazona plane or nearly plane in both sexes, occasionally faintly tumid anteriorly in the female; hind tibiæ purplish, testaceous, or very dull ferruginous.

g^1. Hind femora usually not fasciate; hind tibiæ testaceous or reddish, sometimes basally purplish above; subgenital plate of male with a relatively shallow apical U-shaped fissure, but little deeper than broad . . . . 27. *alutacea.*

g^2. Hind femora usually fasciate; hind tibiæ dark purple; subgenital plate of male cleft narrowly, almost to the base . . . 28. *obscura.*

f^2. Dorsum of metazona distinctly tumid in the female and sometimes in the male; hind tibiæ coral red or purplish.

g^1. Flavo-testaceous; fore and middle femora of male very stout; hind femora generally conspicuously fasciate; hind tibiæ purplish or ferruginous . . . . 29. *lineata.*

g^2. Fore and middle femora of male only moderately stout; hind femora never fasciate; hind tibiæ coral red.

h^1. Flavo-testaceous, the dorsum of prozona, except for stripe, much infuscated . . . . 30. *albolineata.*

h^2. Nearly uniform olivaceous, except for the yellow dorsal stripe.

31. *venusta.*

e^2. Lateral lobes of prozona with a conspicuous black-edged pallid stripe below the middle . . . . 32. *mexicana.*

d^2. Pronotum with no median light colored stripe, or if a feeble one occurs, it terminates with the prozona.

e^1. Wings nowhere roseate.

f^1. Prozona neither tectate nor tumid, with an obscure broad median stripe, not passing the prozona . . . . 33. *separata.*

f^2. Prozona more or less tectate, and, at least in the female, tumid, without a median stripe.

g^1. Superior carinæ of hind femora obscurely serrate; inner spines of hind tibiæ but little longer than depth of tibiæ.

h^1. Prozona not arched longitudinally; pronotum of male not more than half as long again as greatest dorsal width of metazona, its posterior margin distinctly obtusangulate; hind tibiæ red. 34. *shoshone.*

h^2. Prozona feebly arched longitudinally; pronotum of male distinctly more than half as long again as greatest dorsal width of metazona, its posterior margin rather feebly obtusangulate; hind tibiæ testaceous (?) . . . . 35. *obliquata.*

g^2. Superior carinæ of hind femora distinctly serrate; inner spines of hind tibiæ nearly twice as long as depth of tibiæ . . 36. *perturbans.*

e^2. Wings roseate distally . . . . 37. *bicittata.*

a^2. Antennæ of male (those of female always relatively shorter) not or hardly more than, often less than, one fourth longer than the head and pronotum together.

b^1. Prozona more or less strangulate (especially in female ?), narrower than the head exclusive of the eyes, the metazona somewhat abruptly and not gradually expanded and bullate.

c^1. Prozona transversely rotundate, though feebly and delicately carinate; metazona posteriorly rotundato-subrectangulate.

d^1. Anal area of tegmina at broadest one third broader than the interspace between the eyes; anal cerci of male apically rounded; metazona about one half wider than middle of prozona . . . . 38. *peregrina.*

d^2. Anal area of tegmina no broader or scarcely broader than the interspace between the eyes; anal cerci of male distinctly emarginate apically, the lower lobe the longer; metazona about one third wider than middle of prozona . . . . 39. *paranensis.*

c^2. Prozona distinctly tectate and bluntly carinate; metazona posteriorly very obtusangulate and broadly rounded . . . . 40. *exsul.*

b^2. Prozona not strangulate, no narrower than the head exclusive of the eyes, the metazona gradually and regularly expanding posteriorly to a greater or less degree, never bullate.

c^1. Of large size. Pronotum scarcely or not at all tectate, the median stripe broad, the posterior margin obtusangulate and rounded; tegmina distinctly maculate or obliquely strigate; male cerci tapering from base to apex.

d^1. Tegmina feebly if at all pantherine in markings, the costal area immaculate.

e^1. Markings of distal half of tegmina composed of longitudinal streaks by the more or less interrupted infuscation of the longitudinal veins, enforced by a partial infuscation of the adjoining cross-veins * . . . 41. *pallens.*

* These interruptions, however, often occur at similar intervals on adjoining veins, and so give rise also to a more or less noticeable transverse arrangement, but this is less conspicuous than the longitudinal disposition.

e^2. Markings of distal half of tegmina composed of fuscous maculations, generally feeble, arranged in obliquely transverse series at right angles to the veins (much as in *S. americana*), the transverse cross veins at such points infuscated equally throughout . . . . 42. *cancellata.*

d^2. Tegmina distinctly pantherine in markings, the costal area maculate. 43. *americana.*

c^2. Of small size. Pronotum distinctly and strongly tectate, the median stripe narrow, the posterior margin rectangulate or even acutangulate, at least in the male; tegmina immaculate or very feebly maculate; male cerci of subequal breadth . . . . 44. *damnifica.*

1. Schistocerca gracilis sp. nov.

One of the smallest and slenderest of the genus, fusco-testaceous, obscurely marked with fuscous. Head fusco-testaceous; frontal costa subequal, a little expanded basally, strongly sulcate excepting above, coarsely punctate, the margins flavo-testaceous; eyes much longer than the genæ below them; antennæ fulvo-testaceous. Pronotum compressed, subequal, hardly expanding on the metazona, where the width does not exceed that at eyes, fusco-testaceous with a ferruginous tinge, the metazona somewhat infuscated on the disk, the lateral lobes immaculate but a little pallescent centrally; prozona not tectate, of the same length as the metazona, anteriorly produced and well rounded, rather delicately scabrous, the median carina slight but distinct and slender, more pronounced on the metazona, which is delicately scabro-punctate, the posterior angle rectangulate, hardly rounded. Prosternal spine rather slender, rather short, equal, blunt, a little retrorse. Tegmina slender, much longer than the body, fusco-testaceous sprinkled, especially in the distal half, with slight and not very dark fuscous maculations, rather irregularly scattered throughout; wings apparently vitreous.* Fore and middle femora slender; hind femora rather small, but little surpassing the abdomen, fusco-ferruginous, with a somewhat hoary outer face, the upper carinæ scarcely serrate; hind tibiæ ferruginous, the spines black tipped. Anal cerci fully twice as long as basal breadth, tapering slightly, bent a little inward at the middle, the apex truncate and feebly emarginate, the angles rounded; subgenital plate a little upcurved, scaphiform, but tapering regularly as seen from above and compressed, apically acuminate and fissate half way to the base, the angles acute.

* The specimen is in too fragile condition to be spread.

Length of body, 26 mm.; antennæ, 12.5+ mm.; tegmina, 28 mm.; hind femora, 16 mm.

1 ♂. South America.

2. Schistocerca aurantia sp. nov.

Of moderate size and stoutness, fusco-testaceous somewhat obscured with fuscous. Head rather large, nearly uniform fusco-testaceous, above with feeble, more or less divergent, dull fuscous stripes; frontal costa subequal, not very broad, punctate, deeply sulcate below the ocellus; eyes narrow elliptical, very much longer than the infraocular portion of the genæ; antennæ testaceous, the distal half infuscated. Pronotum well arched but not tectate, expanding slightly on the metazona so as to be about as broad as at the eyes, with a feeble median carina, merely indicated on the prozona, the latter produced anteriorly and rounded, a little shorter than the metazona, scabro-punctate, a little more coarsely than the metazona, the whole pronotum uniform in color except that the metazona is more or less ferruginous, posteriorly rectangulate. Prosternal spine moderate, erect, cylindrical or feebly tapering, blunt. Tegmina considerably longer than the body, moderately slender, testaceous becoming subvitreous distally, maculate with moderately large quadrate or rounded fuscous spots, darker proximally than distally and pretty uniformly distributed in the median area, the costal and anal areas more or less minutely flecked with fuscous; wings honey-infumate, the veins flavous and the cross-veins fusco-flavous, with a slight sprinkling of fuscous dots apically. Fore and middle femora not inflated in the male; hind femora scarcely surpassing the abdomen, fusco-ferruginous, the outer face whitish, the carinæ with the serrations marked with fuscous; hind tibiæ fusco-ferruginous verging on purplish, the spines luteous, apically black. Male cerci nearly twice as long as basal breadth, tapering only a little, apically truncate and broadly emarginate; subgenital plate narrowly and rather deeply fissate apically.

Length of body, ♂, 31 mm., ♀, 46 mm.; antennæ, ♂, 15.5 mm., ♀, 16 mm.; tegmina, ♂, 33 mm., ♀, 44.5 mm.; hind femora, ♂, 19 mm., ♀, 27 mm.

1 ♂, 8 ♀. Mexico, Packard; Yucatan, Schott; Meriden, Yucatan; Realejo, Nicaragua, April, McNeil.

The male, from Nicaragua, may not belong here; the wings are almost clear hyaline, but the specimen has been long immersed in spirits and is decolored.

3. Schistocerca carinata sp. nov.

?? *Acridium scutellare* Walk., Cat. Derm. Salt. Brit. Mus., III. 579 (1870). Cf. No. 25, below.

Slightly above the ordinary size and moderately stout, fusco-testaceous with an olivaceous tinge. Head rather large, dull testaceous, the prominences infuscated, with a slender suborbital, genal, obscure fuscous streak and usually a pair of slender, diverging, fuscous streaks on the vertex; eyes considerably longer than the infraocular portion of the genæ, prominent in the male; antennæ flavous or rufous, sometimes infuscated, especially on distal half. Pronotum well arched and very distinctly carinate so as almost to appear tectiform, the metazona enlarging so as to be a little broader than width at eyes, at least in the female, the posterior margin feebly more than rectangulate, the angle very narrowly rounded; prozona produced and rounded anteriorly, somewhat shorter than the metazona, more or less infuscated on the disk, with obscure pallid quadrate patches on the lateral lobes. Prosternal spine moderate, subconical, erect, blunt. Tegmina much longer than the abdomen, obscure olivaceo-testaceous, very obscurely cloudy-maculate with fuscous throughout, substrigate distally; wings vitreous, washed in the faintest manner with aurantio-fuliginous, nowhere maculate. Fore and middle femora scarcely enlarged in the male; hind femora ferrugineo-testaceous, the outer face dull ivory white, the inner portion of the upper face often with a pair of distant fuscous blotches; hind tibiæ purplish testaceous, the spines luteous with black tips. Male cerci more than twice as long as broad, straight, tapering slightly throughout, truncate and very feebly emarginate apically; subgenital plate rather small, elongate, apically acuminate as seen laterally, the apical fissure U-shaped and moderately deep.

Length of body, ♂, 31 mm., ♀, 55 mm.; antennæ, ♂, 14 mm.; tegmina, ♂, 33 mm., ♀, 54 mm.; hind femora, ♂, 17.5 mm., ♀, 30 mm.

1 ♂, 6 ♀. San Diego, Cal., Crotch; Sierra Nola, Mex., Dec. 3–6, Palmer; Orizaba, Mex., Jan. (Bruner); Vera Cruz, Mex., Heyde (Bruner).

4. Schistocerca columbina.

Gryllus ægyptius Thunb., Mém. Acad. St. Pétersb., V. 247 (1815) t. Stål [misnomer].
Gryllus columbinus Thunb., Loc. cit., IX., 399, 425 (1824).
Acridium (*Schistocerca*) *columbinum* Stål, Rec. Orth., I. 67 (1873).
Schistocerca columbina Brunn.-Redt., Proc. Zoöl. Soc. Lond., 1892, 210 (1892).
Gryllus occidentalis Thunb., Loc. cit., IX. 400, 429 (1824) t. Stål.

This species was originally described from St. Bartholomew in the West Indies, and has been reported from other islands, — St. Vincent's, Grenada, Martinique, and Trinidad, as well as from Mexico, Costa Rica, Nicaragua, Guatemala, Panama, Colombia, Venezuela, Surinam, Brazil, and Peru. I have seen specimens only from Costa Rica, Underwood (Bruner); San Mateo del Mar, Tehuantepec, Feb., in lagoons, Sumichrast; and Panama, besides one marked Central America.

5. Schistocerca crocotaria sp. nov.

Slightly above the ordinary size and moderately stout, olivaceo-testaceous, more or less infuscated. Head rather large, olivaceo-testaceous, with faint diverging fuscous stripes on the vertex, the front rather densely punctate with pale ferruginous; frontal costa subequal, feebly sulcate below the ocellus; eyes considerably longer than the infraocular portion of the genæ; antennæ luteous, apically ferruginous. Pronotum well arched, scarcely subtectate, the metazona enlarging so as to be slightly broader at its greatest dorsal width than at the eyes, distinctly shouldered laterally; prozona very slightly produced and broadly rounded in front, bluntly punctate, slightly shorter than the posteriorly rectangulate, rather finely and sharply punctate metazona; whole pronotum olivaceo-testaceous, more or less ferruginous on disk, especially on metazona, obscurely mottled with ferruginous on lateral lobes, the median carina distinct throughout, but especially on metazona. Prosternal spine moderately stout, cylindrical, very blunt, erect or suberect. Tegmina much longer than the body, rather broad, olivaceo-testaceous, rather obscurely maculate with faint fuscous, distally in irregularly oblique broken transverse bands; wings subvitreous, faintly aurantiate throughout, with very feeble signs of maculation apically in anterior area. Hind femora reaching tip of abdomen, moderately stout, flavo-olivaceous on outer, inner, and inner-superior faces on an olivaceous ground, the hind tibiæ flavo-olivaceous with a ferruginous tinge, the spines luteous with black tips.

Length of body, 54 mm.; antennæ, 19 mm.; tegmina, 53 mm.; hind femora, 31 mm.

5 ♀. Chontales, Nicaragua; Realejo, Nicaragua, April, McNeil.

6. Schistocerca interrita sp. nov.

Size and form of the last preceding, ferrugineo-testaceous. Head moderately large, of the ground color with obscure fuscous markings;

frontal costa subequal, sulcate throughout; eyes scarcely longer than the infraocular portion of the genæ; antennæ ferruginous. Pronotum well arched, in no way tectate but with distinct and sharp median carina, ferruginous with feeble fuscous maculations on the lateral lobes (which have also below the middle an obscure pallid spot), widening considerably on the metazona, so as to be considerably broader than at the eyes, the prozona scarcely produced anteriorly, distinctly shorter than the metazona, which is faintly obtusangulate behind, the angle narrowly rounded. Prosternal spine moderate, cylindrical, blunt, retrorse but not arcuate. Tegmina extending much beyond the abdomen, moderately broad, testaceous or ferrugineo-testaceous, with distinct subpantherine fuscous markings of rather large size extending from base to tip; wings vitreous, the veins luteous. Hind femora ferrugineo-testaceous with hoary outer face, the serrations of the upper carinæ fuscous; hind tibiæ pale ferruginous, the spines with black tips.

Length of body, 45 mm.; antennæ, 17+ mm.; tegmina, 50 mm.; hind femora, 28 mm.

2 ♀. Peru, H. Edwards (Mus. Comp. Zoöl., Scudder).

7. Schistocerca camerata sp. nov.

Compact and bulky, somewhat above the medium size, ferrugineo-testaceous more or less infuscated. Head ferrugineo-testaceous, mottled posteriorly with faint plumbeo-fuscous and with a pair of divergent fuscous streaks behind upper edge of eyes; frontal costa subequal, slightly narrower at the ocellus, deeply sulcate at and below the ocellus; eyes narrower than usual, distinctly longer than the infraocular portion of the genæ; antennæ luteo-testaceous. Pronotum distinctly tectate, with very coarse and prominent median carina, which is free from the very obscure and faint infuscation of the remainder; prozona scabro-punctate, produced and subangulate anteriorly, but little shorter than the not very profusely punctate metazona; the latter enlarges but little, but is shouldered posteriorly and just broader than at the eyes, the hind margin faintly obtusangulate, the angle rather narrowly rounded. Prosternal spine short, stout, cylindrical, blunt, erect. Tegmina extending but little beyond the abdomen, rather broad, ferrugineo-testaceous, rather profusely and somewhat obscurely maculate throughout, except the anal area, with fuscous, the maculations in the distal half having a tendency to an obliquely transverse direction; wings impure vitreous, with luteous veins. Hind femora

dull testaceous, the outer face faintly hoary, the carinæ punctate with fuscous at the serrations, the genicular arc black; hind tibiæ dull dark purplish, the spines luteous with black tips.

Length of body, 49 mm.; antennæ, 14+ mm.; tegmina, 44 mm.; hind femora, 28 mm.

3 ♀. Sinaloa, Mex., Koels, Behrens.

8. Schistocerca mellea sp. nov.

Of medium size and moderately stout, fusco-testaceous with a ferruginous tinge. Head ferrugineo-testaceous, with the margins of the frontal costa and facial carinæ punctate with fuscous, a pair of diverging fuscous stripes on the vertex and a genal stripe below the eyes; frontal costa slightly narrowed just below the ocellus and feebly sulcate, excepting above; eyes a little tumid in the male, much longer than the infraocular portion of the genæ; antennæ ferrugineo-testaceous. Pronotum well arched transversely, in no way tectate, the median carina faint excepting on the metazona of the female, where it is slight; prozona obscurely ruguloso-punctate, slightly and scarcely angularly produced anteriorly, a very little shorter than the rather finely punctate metazona, which enlarges considerably posteriorly, so as to be considerably broader than at the eyes, and is posteriorly rectangulate, or in the female faintly obtusangulate; the whole pronotum is ferrugineo-testaceous, the disk, at least in the female, strigate and blotched with fuscous, leaving clear a broad median stripe, the lobes irregularly maculate with fuscous, the middle with a longitudinal fuscous bar, all of which is very obscure in the male. Prosternal spine erect, moderately slender, conico-cylindrical, blunt. Tegmina extending considerably beyond the abdomen, not very slender, ferrugineo-testaceous, profusely and distinctly maculate throughout with fuscous, in the distal half arranged rather conspicuously in transversely oblique stripes; wings honey yellow with a smoky tinge, apically maculate in the upper area. Fore and middle femora not enlarged in the male; hind femora about reaching the tip of the abdomen, ferrugineo-testaceous with hoary outer face, which is punctate with black, as are also the serrations of the carinæ; hind tibiæ ferrugineo-testaceous, the spines pallid with black tips. Male cerci moderately slender, feebly tapering, about twice as long as basal breadth, apically truncate and feebly and broadly emarginate; subgenital plate rather elongate, scaphiform, apically fissate narrowly half way to the base, the flaps so formed acutangulate, the angles rounded.

Length of body, ♂, 30 mm., ♀, 47 mm.; antennæ, ♂, 13.5 mm., ♀, 12+ mm.; tegmina, ♂, 32 mm., ♀, 47 mm.; hind femora, ♂, 18 mm., ♀, 25 mm.

1 ♂, 1 ♀. Vera Cruz, Mexico, Heyde (Bruner).

9. Schistocerca zapoteca sp. nov.

Of moderate size and stoutness, but in these respects with considerable disparity between the sexes, fusco-testaceous with a slight ferruginous tinge. Head rather prominent, testaceous, flecked and more or less obscured with fuscous, with a pair of divergent fuscous stripes bordering the flavo-testaceous median stripe which marks the vertex; frontal costa a little contracted at the ocellus, sulcate at and below the same, flavous at the margins; eyes prominent in the male, much longer than the infra-ocular portion of the genæ; antennæ flavo-testaceous, in the male a third as long again as head and pronotum together. Pronotum somewhat compressed, well arched, hardly tectate, feebly and very bluntly carinate, the disk ferrugineo-fuscous, sometimes strigate on the metazona, with a distinct, rather narrow, median testaceous stripe, broader in the female than in the male, the lateral lobes broader than deep, testaceous, mottled or obscured or occasionally vittate with fuscous; prozona produced anteriorly and rather strongly rounded, a little shorter than the metazona, which is posteriorly rectangulate with narrowly rounded angle, and expands but little even in the female so as hardly to exceed the width at the eyes. Prosternal spine slender, feebly tapering, blunt, erect. Tegmina extending far beyond the abdomen, moderately slender, ferrugineo-testaceous, rather profusely but feebly maculate with fuscous, mainly by the infuscation of cross-veins, occasionally disposed in obliquely transverse stripes on the distal half; wings vitreous or very faintly infumate apically, occasionally faintly maculate apically in the anterior area, the veins luteo-ferruginous. Fore and middle femora scarcely thickened in the male; hind femora rather slender, reaching beyond the abdomen, luteo-testaceous, flecked and punctate with fuscous, often tinged more or less with ferruginous, especially on the distal half, occasionally flavescent basally; hind tibiæ dark dull purple, the spines luteous with black tips. Male cerci twice as long as broad, equal, straight, apically truncate and mesially emarginate, the angles rounded; subgenital plate tapering, scaphiform, apically compressed, deeply cleft, the fissure closed.

Length of body, ♂, 28 mm.. ♀, 40 mm.; antennæ, ♂, 13 mm., ♀, 14.5 mm.; tegmina, ♂, 29 mm., ♀, 43 mm.; hind femora, ♂, 18 mm., ♀, 26 mm.

21 ♂, 13 ♀. Venis Mecas, Mex., Jan. 6, Palmer; Mexico, April, Sumichrast, Botteri; Guatemala, Van Patten; Costa Rica, Underwood (Bruner); South America.

10. Schistocerca vaga.

Acridium vagum Scudd.!, Proc. Bost. Soc. Nat. Hist., XVIII. 269 (1876).
Schistocerca vaga Brun., Proc. U. S. Nat. Mus., XII. 187 (1890).

I have received this species from California, H. Edwards; Fresno, April 27 (Stanf. Univ.), Pasadena, June (Stanf. Univ.), Los Angeles, March (Bruner), South Santa Monica, July 30, Morse, Colton, July 17, Morse, San Bernardino, July 15, Morse, Palm Springs, July 12, Morse, and San Diego, Cal., Edwards, Crotch, and Mohave Desert, Cal.; Ft. Whipple, Palmer, and Yuma, Ariz., July 7, Morse; Mesilla, N. Mex., Cockerell, Oct. 18, Morse; San Antonio, Sept. 18–27, Palmer, Uvalde, July, Palmer, and El Paso, Tex., Aug., Dunn (Bruner); Guadalupe Isl., off Lower California, Palmer; Cape St. Lucas, Lower Cal., Xantus; Matamoras, Tamaulipas, Couch, Uhler; San Pedro, May 20, Palmer, and Montelovez, Coahuila, Sept. 20, Palmer; Sonora, Schott; Bledos, Mex., Oct. 1, Palmer; Sierra Nola, Mex., Dec. 3–6, Palmer; Mexico City, Palmer; Jalapa, Mex., June 22 (Bruner), Durango, Mex., Palmer, and Jalasco, Mex., Berendt; and Realejo, Nicaragua, April, McNeil.

11. Schistocerca simulatrix.

? *Cyrtacanthacris simulatrix* Walk., Cat. Derm. Salt. Brit. Mus., IV. 610 (1870).
? *Acridium simulatrix* [sic] Thom., Rep. U. S. Geol. Surv. Terr., V. 280 (1873).

Originally described from San Domingo. I have a specimen which appears to belong here, which comes from Inagua, Bahamas.

12. Schistocerca pyramidata sp. nov.

Of medium size and stoutness, fusco-testaceous. Head rather large, pale testaceous, the face generally much infuscated, especially on the prominent parts, with a ferruginous tinge, posteriorly striped with fuscous and the vertex with a pair of diverging fuscous stripes running from the front of the fastigium or even the median ocellus backward, leaving between them a broad clear luteo-testaceous median band; frontal costa subequal, deeply sulcate at and below the ocellus; eyes prominent in the male, much, in the male very much, longer than the infraocular portion of the genæ; antennæ considerably more than a third longer than the

head and pronotum together in the male, luteous. Pronotum well arched, in no way tectate, but with a delicate percurrent median carina, in the middle of a regularly narrowing but percurrent luteous or ferrugineo-luteous median stripe, the rest of the disk fuscous, often longitudinally strigate with testaceous on the metazona; lateral lobes ferrugineo-testaceous, much mottled and sometimes longitudinally strigate with fuscous, a paler spot generally appearing on the upper part of the prozona; prozona a little produced anteriorly and rounded, a little shorter than the metazona, which is posteriorly rectangulate, the angle rounded not very narrowly. Prosternal spine rather slender, slightly tapering, blunt, straight, slightly inclined. Tegmina extending considerably beyond the abdomen, moderately slender, testaceous, in the male nearly immaculate, in the female distinctly but not very profusely maculate with fuscous throughout the median area, the maculations of the distal half small and obscurely arranged in obliquely transverse lines; wings faintly tinged, especially in the anal area, with pale citron, apically very faintly fuliginous, nowhere maculate. Fore and middle femora not enlarged in the male; hind femora attaining (♀) or surpassing (♂) the end of the abdomen, dull testaceous with the outer face dull ivory white, punctate with fuscous along the carinæ; hind tibiæ dull purplish testaceous, the spines luteous with black tips. Male cerci of subequal breadth, about twice as long as basal breadth, apically a little obliquely truncate and considerably emarginate mesially, the lobes thus formed rounded, the lower somewhat the longer; subgenital plate slender, elongate, scaphiform, apically very deeply fissate, the acute angles only slightly rounded.

Length of body, ♂, 37 mm., ♀, 53 mm.; antennæ, ♂, 15.5 mm., ♀, 18 mm.; tegmina, ♂, 36 mm., ♀, 53 mm.; hind femora, ♂, 20 mm., ♀, 31.5 mm.

2 ♂, 5 ♀. Cuernavaca, Mexico, May, Sept., Barrett (Morse).

18. **Schistocerca desiliens** sp. nov.

Of moderately large size and moderate stoutness with considerable disparity between the sexes, ferrugineo-testaceous, considerably infuscated. Head not very large, ferrugineo-testaceous, testaceous posteriorly, all the carinæ marked with fuscous, and a pair of diverging fuscous stripes on the vertex, enclosing a broad median luteo-testaceous band, as in the last species; frontal costa subequal, deeply sulcate at and below the ocellus; eyes somewhat prominent, especially in the male, distinctly (♂) or scarcely (♀) longer than the infraocular portion of the genæ; antennæ

more than half as long again as the head and pronotum together in the male, luteous, faintly infuscated apically. Pronotum well arched, in no way tectate, but with a delicate percurrent median carina in the middle of a gradually diminishing but percurrent luteo-testaceous median stripe, the remainder of the disk ferrugineo-fuscous, the lateral lobes the same with a strongly oblique anterior and inferior luteo-testaceous patch, edged above with fuscous fading superiorly; prozona roundly produced anteriorly, slightly shorter than the metazona, which is very slightly broader than at the eyes, posteriorly rectangulate (♂) or faintly obtusangulate (♀), the angle narrowly rounded. Prosternal spine moderate, cylindrical, blunt, erect or suberect. Tegmina extending well beyond the abdomen, slender, with a pallid luteous streak basally in the costal area, in the male otherwise immaculate or nearly so, in the female sparsely and rather feebly maculate in the median area and particularly along the median line, all the maculations small; wings vitreous, with an exceedingly feeble infumation, most distinct apically. Fore and middle femora not enlarged in the male; hind femora ferrugineo-testaceous, with hoary outer face and the carinæ punctate with fuscous; hind tibiæ ferrugineo-testaceous, the spines luteous with black tips. Male cerci very small, straight, hardly twice as long as broad, tapering to a blunt rounded tip; subgenital plate slender, haustrate, somewhat compressed, subacuminate, apically narrowly and not very deeply fissate.

Length of body, ♂, 31 mm., ♀, 55 mm.; antennæ, ♂, 14.5 mm., ♀, 18 mm.; tegmina, ♂, 31 mm., ♀, 56 mm.; hind femora, ♂, 17 mm., ♀, 32 mm.

1 ♂, 4 ♀. Rio de Janeiro, Brazil, Nov. (Mus. Comp. Zoöl.); Victoria, Brazil, May (Bruner).

I know of no species of Schistocerca in which the male cerci are so narrow at apex as here; the next species is the most closely allied in that respect.

14. Schistocerca flavofasciata.

Acrydium flavofasciatum DeGeer, Mém., III. 488, pl. 40, fig. 8 (1773).
Acridium (Schistocerca) flavofasciatum Stål, Rec. Orth., I. 67 (1873).
Gryllus nitens Thunb., Mém. Acad. St. Pétersb., V. 236 (1815) t. Stål.
Gryllus fimbriatus Thunb., Loc. cit., IX. 428 (1824) t. Stål.
Gryllus lividus Thunb., Loc. cit., IX. 428 (1824) t. Stål.
Acridium longipenne Burm., Handb. Ent., II. 632 (1838) t. Stål.

The only specimens I have seen are from Rio de Janeiro, Nov. (Mus. Comp. Zoöl.), and Corumba, Brazil, March, April (Mus. Comp. Zoöl.). It was originally described from Brazil.

15. **Schistocerca infumata** sp. nov.

Of large size and moderate stoutness, dark olivaceo-fuscous. Head not very large, olivaceo-fuscous, with a subocular genal fuscous streak, and a pair of divergent fuscous streaks on the vertex, enclosing a median luteo-testaceous stripe; frontal costa subequal, deeply sulcate at and below the ocellus; eyes a little prominent in the male, distinctly (♂) or scarcely (♀) longer than the infraocular portion of the genæ; antennæ barely a third longer than the head and pronotum together in the male, luteous or luteo-testaceous. Pronotum well arched but feebly subtectate, with distinct percurrent median carina in the middle of a posteriorly attenuating luteo-testaceous median stripe edged with fuscous, the rest of the pronotum dark olivaceo-fuscous with an oblique inferior fuscous cloud or stripe on the lateral lobes, the whole pronotum gradually enlarging posteriorly, so that the metazona is considerably (♀) or a little (♂) wider than at the eyes; prozona angularly produced anteriorly, the angle rather narrowly rounded, but little shorter than the metazona, which is posteriorly rectangulate (♂) or faintly obtusangulate (♀), the angle not very narrowly rounded. Prosternal spine slight, cylindrical, blunt, erect. Tegmina extending far beyond the abdomen, moderately slender, olivaceo-testaceous, immaculate; wings distinctly infumate throughout. Fore and middle femora not enlarged in the male; hind femora dark testaceous, the outer face and genicular lobe ivory white, the carinæ punctate with fuscous, occasionally the other faces more or less hoary; hind tibiæ dull ferruginous, the spines luteous (or in the female the outer spines luteous, the inner ferruginous) with black tips. Male cerci very small for this genus, half as long again as broad, the lower margin straight, the upper rounded, and tapering so as to be at the truncate apex hardly a third as broad as at broadest. Subgenital plate straight, long, scaphiform, hardly compressed, apically deeply and still more widely emarginate to form a U-shaped fissure with diverging sides, the angles subacuminate. Whole body and legs pilose.

Length of body, ♂, 33.5 mm., ♀, 58 mm.; antennæ, ♂, 14 mm., ♀, 18 mm.; tegmina, ♂, 38 mm., ♀, 56 mm.; hind femora, ♂, 21.5 mm., ♀ 32 mm.

7 ♂, 3 ♀. Montevideo, Uruguay, Meyer-Dür; Brazil, Janson.

16. Schistocerca æqualis sp. nov.

Of fair size and moderately slender, fusco-testaceous. Head moderately large, fusco-testaceous, the vertex fuscous except a broad median ferrugineo-luteous band; frontal costa subequal, sulcate below the ocellus; eyes rather prominent, very much longer than the infraocular portion of the genæ; antennæ at least a third longer than the head and pronotum together, ferrugineo-luteous. Prozona well arched, in no way tectate, but with distinct and delicate percurrent median carina, in the middle of a rather broad and equal percurrent ferrugineo-luteous stripe, the rest of the disk fuscous, the lateral lobes fusco-testaceous, with an oblique inferior fuscous stripe, below which they are testaceous; prozona roundly produced anteriorly, about as long as the metazona, which enlarges but slightly and is narrower than at the eyes and posteriorly rectangulate or perhaps faintly obtusangulate, the angle rounded. Prosternal spine rather long, erect, cylindrical, bluntly tapering apically. Tegmina extending well beyond the abdomen, slender, immaculate, ferrugineo-testaceous, the costal and anal areas testaceous; wings very faintly infumate with a slight citron tinge. Fore and middle femora not enlarged; hind femora rather slender, slightly surpassing the abdomen, ferrugineo-testaceous, the outer face hoary, feebly punctate with fuscous on the carinæ; hind tibiæ dull purplish or ferruginous, the spines luteous with black tips. Male cerci subequal, about half as long again as broad, inbent at the middle, apically angularly emarginate above the middle, the lower lobe projecting; subgenital plate short scaphiform, almost haustrate, apically U-shaped, the emargination deeper than broad, and the angles subacute.

Length of body, 35 mm.; antennæ, 13.25+ mm.; tegmina, 36 mm.; hind femora, 19 mm.

2 ♂. Demerara, British Guiana.

17. Schistocerca maya sp. nov.

Below the medium size and moderately slender, testaceous, more or less infuscated. Head moderately large, ferrugineo- or luteo-testaceous, the vertex with a pair of fuscous stripes bordering a ferrugineo-luteous median band; frontal costa subequal, sulcate at and below the ocellus; eyes moderately prominent, much longer than the infraocular portion of the genæ; antennæ more than a third longer than the head and pronotum together, ferruginous. Pronotum well arched, in no way tectate, with a delicate median carina in a (sometimes obscured) ferrugineo-luteous dorsal

stripe, the rest of the disk fuscous, the lateral lobes ferrugineo-testaceous, unmarked, or at most feebly clouded with fuscous; prozona produced and angulato-rotundate in front, as long as the metazona, which enlarges but little, is narrower than at the eyes and posteriorly rectangulate and narrowly rounded. Prosternal spine moderate, conical, blunt, feebly retrorse. Tegmina much surpassing the abdomen, immaculate or very faintly and most obscurely clouded with fuscous, ferrugineo-testaceous, the anal area lutescent; wings vitreous with luteous veins. Fore and middle femora not enlarged; hind femora ferrugineo-testaceous, with hoary outer face; hind tibiæ ferruginous, the spines luteous with black tips. Male cerci subequal, fully half as long again as broad, a little obliquely truncate apically, the lower posterior angle distinctly produced and rounded; subgenital plate scaphiform, subacuminate, apically fissate to the base, the fissure closed.

Length of body, 31 mm.; antennæ, 13 mm.; tegmina, 28.5 mm.; hind femora, 18 mm.

3 ♂. Venis Mecas, Mexico, Jan. 6, Palmer; San Mateo del Mar, Tehuantepec, in lagoons, Feb., Sumichrast.

The description is based mainly on the Mexican specimen, and the others may possibly not belong here. All have been immersed in alcohol.

18. Schistocerca australis nom. nov.

Acridium occidentale Scudd.!, Proc. Bost. Soc. Nat. Hist., XII. 339 (1869).
Acridium (*Schistocerca*) *occidentale* Scudd., Loc. cit., XVII. 274 (1875).

The name is here changed, as the name *occidentalis* was given by Thunberg to another species of Schistocerca, placed by him in Gryllus; see No. 4, above.

I have specimens before me from Rio de Janeiro, U. S. Expl. Exp., Thayer Exp., Mrs. Davis (Mus. Comp. Zoöl.); Brazil, Linden (Mus. Comp. Zoöl.); Santarem and Cudais, Brazil, Thayer Exp. (Mus. Comp. Zoöl.); Paramaribo, Dutch Guiana, Richardson (Mus. Comp. Zoöl.); and the Napo or Maranon River, eastern Peru.

19. Schistocerca gulosa sp. nov.

Large and bulky, ferrugineo-testaceous. Head large, ferrugineo-testaceous, obscurely marked with fuscous and especially with a pair of very divergent stripes on the vertex; frontal costa subequal, faintly broadening below, sulcate below the ocellus; eyes much longer than the

infraocular portion of the genæ; antennæ rufous. Pronotum well arched, in no way tectate, but with a distinct though slight median carina, ferrugineo-testaceous, the front edge narrowly fuscous, the disk with exceedingly obscure infuscation, leaving a clear dorsal stripe scarcely perceptible, the lateral lobes obscurely mottled with fuscous and with a mesial longitudinal fuscous stripe; prozona produced and rounded anteriorly, a little shorter than the metazona, which broadens considerably behind so as to be very much broader than at the eyes, and is obtusangulate, the angle a little rounded. Prosternal spine rather small, erect, subconical, blunt. Tegmina extending far beyond the abdomen, moderately broad, ferrugineo-testaceous, faintly feebly and sparsely maculate with fuscous in one- or two-celled patches; wings vitreous with a faint citron hue basally, all the veins luteous or ferruginous. Hind femora ferrugineo-testaceous, the outer face ivory white, the carinæ punctate with fuscous; hind tibiæ dull purplish, the spines luteous with black tips.

Length of body, 52 mm.; tegmina, 54 mm.; hind femora, 28.5 mm.

1 ♀. Demerara, British Guiana.

20. Schistocerca bogotensis sp. nov.

Below the average size and not very stout, ferrugineo-testaceous, much infuscated. Head moderately large, ferrugineo-testaceous, the frontal costa much infuscated, especially at the margins, whence a fuscous stripe proceeds on either side backward across the vertex, leaving a broad subferruginous median band; frontal costa subequal, sulcate below the ocellus; eyes considerably longer than the infraocular portion of the genæ. Pronotum well arched, in no way tectate, but with a sharp though slight median carina in the middle of a broad subequal, but on the metazona slightly attenuated, subferruginous stripe, the rest of the disk deeply infuscated, the lateral lobes ferrugineo-testaceous, blotched with fuscous and testaceous, but not longitudinally striped; prozona a little shorter than the metazona, a little and roundly produced anteriorly, the metazona but little enlarged and hardly exceeding the width at the eyes, posteriorly obtusangulate, the angle broadly rounded. Prosternal spine rather long, erect, subconical, blunt. Tegmina extending well beyond the abdomen, moderately broad, testaceous, maculate with fuscous in the median area, the maculations in distal half obscurely massed in broad oblique bands; wings citrino-infumate, without maculations. Hind femora ferrugineo-testaceous, the outer face dull ivory white; hind tibiæ vinous, the spines vinous with black tips.

Length of body, 49 mm.; tegmina, 46.5 mm.; hind femora, 26 mm.

2 ♀. Bogota, Colombia.

21. Schistocerca inscripta.

Cyrtacanthacris inscripta Walk., Cat. Derm. Salt. Brit. Mus., III. 550 (1870).
Acridium inscriptum Thom., Rep. U. S. Geol. Surv. Terr., V. 228 (1873).

Originally described from Jamaica. I have seen a single specimen from Mandeville, Jamaica, April, Cockerell (Bruner).

22. Schistocerca idonea sp. nov.

Of fully average size and moderately slender, ferrugineo-testaceous, much infuscated. Head rather large, luteo-testaceous, all the prominences marked with fuscous, besides a distinct suborbital genal fuscous stripe, and on the vertex a pair of divergent fuscous stripes on either side of a broad testaceous median stripe, sometimes tinged with ferruginous; frontal costa broadly and rather shallowly sulcate, subequal; eyes shorter than the infraocular portion of the genæ; antennæ rufous. Pronotum well arched, in no way tectate, very faintly strangulate, the median carina delicate, percurrent, lying in the middle of a very broad and equal ferrugineo-testaceous stripe, bordered on either side by a slightly broader posteriorly widening fuscous or ferrugineo-fuscous stripe, occupying the rest of the disk; lateral lobes testaceous with a very broad median slightly oblique longitudinal fuscous stripe, often itself with a median testaceous thread; prozona strongly produced and well rounded in front, slightly shorter than the metazona, which broadens so as to be slightly broader than at the eyes, and is posteriorly obtusangulate, the angle generally very broadly rounded but variable. Tegmina extending far beyond the abdomen, rather slender, testaceous, the costal area with a long luteous streak, the anal area wholly luteous or luteo-testaceous, the median area profusely maculate with fuscous, more or less blended in the proximal half, scattered and more feeble and generally subquadrate in the distal half; wings rather faintly flavo-infumate, immaculate. Hind femora testaceous, the outer face hoary or lutescent below, infuscated along the middle and generally above, the carinæ punctate with fuscous at the serrations; hind tibiæ ferruginous, the spines luteous with black tips.

Length of body, 46 mm.; antennæ, 16.5 mm.; tegmina, 41 mm.; hind femora, 22.5 mm.

3 ♀. Crapada, Brazil, July, Aug. (Mus. Comp. Zoöl.).

23. Schistocerca literosa.

Acridium literosum Walk., Cat. Derm. Salt. Brit. Mus., IV. 620 (1870); Butl., Proc. Zoöl. Soc. Lond., 1877, 88 (1877).
Schistocerca literosa Scudd., Bull. Mus. Comp. Zoöl., XXV. 15, pl. 2, figs. 1, 3 (1893).

This species is known only from the Galapagos, and has been found on Chatham, Hood, Tower, and Charles Islands, the forms occurring on each island, or on all but the last, being distinct enough to be regarded as races, as I have pointed out in the paper above cited, where nine points of distinction are tabulated.

24. Schistocerca melanocera.

Acridium melanocerum Stål, Eug. Resa, Ins., Orth., 326 (1860).
Acridium (Schistocerca) melanocerum Stål, Rec. Orth., I. 65 (1873).
Schistocerca melanocera Brun., Proc. U. S. Nat. Mus., XII. 193 (1889); Scudd., Bull. Mus. Comp. Zoöl., XXV. 11, pl. 2, figs. 5, 6 (1893).
Acridium tibiale Walk., Cat. Derm. Salt. Brit. Mus., III. 582 (1870) t. Walker.

This is known to me only from the Galapagos Archipelago, where it has been found on Charles, Albemarle, Indefatigable, Chatham, Jervis, Barrington, James, and Duncan Islands; but it is also credited by Walker to the "west coast of America." In my paper on the Orthoptera of the Galapagos, quoted above, I have discussed at length the distinct types which appear to be forming on the different islands.

25. Schistocerca rubiginosa.

Acridium rubiginosum Harr.!, MS., Scudd., Bost. Journ. Nat. Hist., VII. 467 (1862).
Schistocerca rubiginosa Morse, Psyche, VII. 105 (1894).
?? *Acridium scutellare* Walk., Cat. Derm. Salt. Brit. Mus., III. 579 (1870). Cf. No. 3, above.

This insect is found along the entire Atlantic coast of the United States from central Massachusetts to Key West, Florida, and in the interior, east of the Great Plains, from as far north as Iowa and Minnesota to the Gulf, and it extends into Mexico and even farther south.

My specimens come from Massachusetts, Sanborn; Wellesley, Aug. 8, Sept. 24, Oct. 10–11 (Morse), Dedham, Aug., Maynard (Morse), Provincetown, Sept. 4–6 (Morse), and Hyannis, Mass., Scudder; Kingston and Wickford, R. I., Aug. 29 (Morse); Connecticut, Uhler, Norton; Thompson, Aug. 6, 9 (Morse), Deep River, Aug. 24 (Morse), North

Haven, Aug. 23 (Morse), New Haven, Aug. 29 (Morse), Smith, Stamford, Aug. 13–17 (Morse), and Greenwich, Conn., Aug. 27 (Morse); Long Island, Sept.; Sparkill, N. Y., Baird; Maryland, Uhler; Middle States, Osten Sacken; Jefferson, Iowa, Sept. 20, Allen; District of Columbia (Bruner); Virginia, Oct. (Bruner); Smithville, Nov. 21, Dingo Bluff, Nov. 15, Parker, Maynard, and Newbern, N. C.; Georgia, Morrison; Florida, Wurdemann; Biscayne Bay, Palmer, and Key West, Fla., Morrison, Palmer, Maynard; Texas, Aug. 19, Belfrage, Lincecum, and Dallas, Tex., Boll; Inagua, Bahamas; Mexico, Schaum; Yucatan, Schott; and Guatemala, Van Patten.

It has also been reported from Staten Island, Davis; New Jersey, Smith; Kentucky, Garman; Illinois, McNeill; Minnesota, Lugger; and Nebraska, Bruner.

26. Schistocerca sonorensis sp. nov.

Of medium size and not very stout, testaceous. Head testaceous with none but the most obscure markings; frontal costa subequal, deeply sulcate below the ocellus; eyes very much longer than the infraocular portion of the genæ; antennæ a third longer than the head and pronotum together, luteous. Pronotum distinctly subtectate with an excessively blunt median carina, testaceous, without markings except a slight indication of a quadrate fuscous patch on the lateral lobes; prozona slightly produced and rounded anteriorly, a very little shorter than the metazona, bluntly rugulose, the metazona punctate but scarcely rugulose, broadening posteriorly so as to be a very little wider than at the eyes, posteriorly obtusangulate, the angle narrowly rounded. Prosternal spine moderate, cylindrical, erect, blunt. Tegmina extending far beyond the abdomen, slender, testaceous, the median area profusely but obscurely maculate, the maculations in the distal half mostly elongate; wings hyaline, with the very faintest possible apical infumation, immaculate. Fore and middle femora not enlarged; hind femora testaceous, the outer face hoary, the inner with feeble fuscous clouds as the basis of fasciation, the carinæ punctate with fuscous on the proximal half; hind tibiæ testaceous, the spines luteous with black tips. Male cerci feebly incurved, tapering gently by the slope of the upper margin, nearly twice as long as middle breadth, apically truncate and minutely emarginate; subgenital plate rather long and slender, scaphiform, apically acuminate on a side view due to the slope of the inferior margin, hardly compressed, apically deeply fissate, the fissure closed.

Length of body, 35 mm.; antennæ, 13.5 mm.; tegmina, 38.5 mm.; hind femora, 20.5 mm.

2 ♂. Sonora, Mexico, Schott.

The specimens have been long immersed in spirits.

27. Schistocerca alutacea.

Acridium alutaceum Harr.!, Ins. Inj. Veg., 139 (1841).
Cyrtacanthacris alutacea Walk., Cat. Derm. Salt. Brit. Mus., IV. 609 (1870).
Schistocerca alutacea Brun., Publ. Nebr. Acad. Sc., III. 26 (1893).
Acridium emarginatum Uhl.!, MS., Dodge, Can. Ent., IV. 15 (1871).

This insect has much the same distribution as *S. rubiginosa*, but is a little less extended on the Atlantic coast, reaching only from extreme southern Massachusetts to northern Florida. It is not only more common than that species at the west but has a wider range there, extending in the north to Montana, Utah, and Nevada, and in the south to New Mexico and even southern California, while it also occurs in northern Mexico.

Specimens at hand come from West Chop, Martha's Vineyard, Mass. (Morse); Farmington, Norton, Deep River, Aug. 24 (Morse), New Haven, Smith, North Haven, Aug. 23 (Morse), and Stamford, Conn., Aug. 10–22 (Morse); Long Island; Middle States, Osten Sacken; Maryland, July 11, Uhler; Newbern, N. C.; Georgia, Morrison, Oemler; Florida, Uhler, and Jacksonville, Fla., Priddey (Bruner); Indiana, Oct. 2, Blatchley (Morse, Scudder); Illinois and southern Illinois, Uhler; Colona, Ill., Aug. 12, McNeill; Minnesota, Bruner; Dallas Co., Aug. 20–24, Allen, and Jefferson, Iowa, Sept. 20, 26, Allen; Nebraska, Dodge; Sidney, Nebr. (Bruner); Valley of the Platte, Hayden; southern Black Hills, Austin; Upper Missouri River, Hayden; Colorado, Baker (Morse), Morrison; Pueblo, Aug. 30–31, Scudder, Denver, Scudder, and Manitou, Col., Aug. 24–25, Scudder; Texas, Pope, Belfrage, Aug. 19, Oct. 13; southwestern Texas, Schaupp (Bruner); San Antonio, Sept. 18–27, Palmer and Dallas, Tex., Boll; Spring Lake Villa, Utah Co., Utah, Aug. 1–4, Palmer; Reno, Nevada; Julian, San Diego Co., Cal., Palmer; Mesilla, N. Mex., June 30, Morse; and Sierra Nola, Mex., Dec. 3–6, Palmer.

It has further been reported from Staten Island, Davis; New York, Beutenmüller; New Jersey, Smith; Kentucky, Garman; and Kansas, Bruner.

28. Schistocerca obscura.

Gryllus obscurus Fabr., Suppl. Ent. Syst., 194 (1798).
Acridium obscurum Burm.!, Handb. Ent., II. 632 (1838).
Acridium olivaceum Serv., Orth., 666 (1839).

This species has a more southern range than the preceding, from which it is with difficulty distinguished, not being known on the Atlantic coast north of North Carolina, though in the west it occurs as far north as Nebraska and even Iowa. It is not known west of eastern Colorado, except in the south, where it occurs in New Mexico; and it is found throughout Mexico.

I have specimens before me from North Carolina, Holder, Uhler, Shute; Dingo Bluff, N. C., Nov. 15, Parker, Maynard; South Carolina, Oemler; Georgia, Morrison; Morris Isl., Geo., Akhurst; Florida, Uhler; Biscayne Bay, Palmer, Green Cove Springs, Boardman, and Cedar Keys, Fla., Palmer; Jefferson, Sept. 20, Allen, and Dallas Co., Iowa, Aug. 1–10, 20–23, Allen; Sidney (Bruner), and Platte River, Nebr., Hayden; Pueblo, Aug. 30–31, Scudder, and Manitou, Col., Aug. 24–25, Scudder; Texas, Lincecum, Belfrage; Dallas, Boll, Bosque Co., Oct. 23, Belfrage, Eagle Pass, Schott, and Carrizo Springs, Tex., Wadgymar (Bruner); White Sands, 30 m. south of Tularosa, Dona Ana Co., N. Mex. 3600′, Aug. 25, Wooton (Morse); Mexico, Uhler; Matamoras, Tamaulipas, Couch, Uhler; Montelovez, Coahuila, Sept. 20, Palmer; Sonora, Schott; Venis Mecas, Mexico, Palmer; Tepic, Mex., Cal. Acad. Sc. (Bruner); and Vera Cruz, Mex., Heyde (Bruner).

I have examined Burmeister's species in the Halle Museum, and this is also the species so named in the Berlin Museum.

29. Schistocerca lineata sp. nov.

Of large size and robust form, pilose, flavo-testaceous, marked with fuscous. Head moderate, flavo-testaceous, often marked with fuscous on the prominent parts, with a distinct, suborbital, genal streak of fuscous, and the whole vertex more or less infuscated except for a median flavo-testaceous stripe; frontal costa subequal, feebly sulcate; eyes somewhat prominent in the male, distinctly longer than (♂) or of about the same length as (♀) the infraocular portion of the genæ; antennæ about half as long again as the head and pronotum together in the male, flavous. Pronotum feebly tectate, with a slight percurrent median carina, the disk much, generally deeply, infuscated, with a not very broad median flavo-

testaceous stripe, the lateral lobes flavo-testaceous, more or less suffused with fuscous, sometimes much infuscated, rarely blotched with fuscous; prozona slightly and roundly produced anteriorly, about as long as the metazona, which is distinctly tumid dorsally in the female, and sometimes in the male, expanding also so as to be about as wide as (♂) or considerably wider than (♀) the breadth at the eyes, posteriorly obtusangulate, the angle broadly rounded. Prosternal spine moderate, erect, bluntly acuminate. Tegmina extending somewhat beyond the abdomen, moderately broad, testaceous or flavo-testaceous, the median area generally heavily infuscated next the flavous anal area, but otherwise immaculate excepting for sometimes, especially in the female, the faintest signs of quadrate maculations transversely arranged in the distal half; wings faint flavous with luteous veins. Fore and middle femora considerably tumid in the male; hind femora flavous, flavo-testaceous or testaceous, generally conspicuously trifasciate with fuscous, the fasciations more or less broken and occasionally considerably reduced; hind tibiæ purplish or ferruginous, the spines luteous with black tips. Male cerci less than half as long again as broad, bent inward at the middle, tapering very little, apically deeply and obliquely emarginate, the lower lobe the longer, more extended and more broadly rounded; subgenital plate short, haustrate rather than scaphiform, the apex deeply cleft in U-shape, the cleft more than twice as deep as broad, the margins parallel, the angles well rounded.

Length of body, ♂, 47 mm., ♀, 59 mm.; antennæ, ♂, 20 mm., ♀, 21.5 mm.; tegmina, ♂, 38.5 mm., ♀, 56 mm.; hind femora, ♂, 23 mm., ♀, 33 mm.

2 ♂, 10 ♀. Barber Co., Kans., Cragin (Bruner); Texas, Lincecum, Belfrage; San Antonio, Tex., Newell (Bruner); Gulf coast of Texas, Aaron; Montelovez, Coahuila, Mex., Sept. 20, Palmer.

80. Schistocerca albolineata.

Acridium albolineatum Thom., Rep. U. S. Geol. Surv. West 100 Mer., V. 897, pl. 43, fig. 1 (1875).

Specimens at hand come from Ames, Iowa (Bruner); Camas Pt., Idaho (Bruner); Mesilla, June 30, Morse, and Las Cruces, N. Mex., Aug. 19 (Bruner); and Grand Cañon, Ariz., July 5 (Bruner). It was originally described as probably from Arizona.

31. **Schistocerca venusta** sp. nov.

Of fully medium size, moderately slender, olivaceous marked with flavous and more or less infuscated. Head not very large, flavo-olivaceous, with a greenish fuscous suborbital genal streak, and a pair of similar divergent stripes on the vertex, darker in color in front of than behind the eyes, bordering a broad median flavous stripe; frontal costa subequal, moderately sulcate below the ocellus; eyes somewhat prominent, especially in the male, distinctly longer than the infraocular portion of the genæ; antennæ more than half as long again as the head and pronotum in the male, flavo-luteous. Pronotum feebly subtectate, olivaceous, sometimes punctate with flavous, the lateral lobes sometimes clouded with dull flavous and always lighter than the disk, which is more or less though never strongly infuscated or of a deeper green, leaving however an ordinarily broad flavous median stripe; median carina slight, percurrent; prozona considerably produced and strongly rounded in front, about as long as the metazona, which expands only a little so as to be only as broad as (♂) or but little broader than (♀) the width at the eyes, the disk more or less tumid, at least in the female, posteriorly obtusangulate, the angle generally broadly rounded. Prosternal spine slender, compressed conical, subacuminate, erect. Tegmina extending considerably beyond the abdomen, moderately slender, olivaceous, immaculate, the edge of the anal area more or less flavous; wings hyaline with green veins. Fore and middle femora slightly enlarged in the male; hind femora not very stout, about reaching the tip of the abdomen, olivaceous, the outer face more or less hoary and basally flavescent, the genicular lobe flavous; hind tibiæ red, the spines luteous with black tips. Male cerci fully half as long again as broad, tapering but little, inbent at middle, apically truncate with rounded angles and mesially emarginate, the lower lobe projecting the most; subgenital plate very short scaphiform, upturned, apically emarginate half way to base, forming a V-shaped incision, generally much deeper than broad, the angles hardly rounded.

Length of body, ♂, 45 mm., ♀, 56 mm.; antennæ, ♂, 20 mm., ♀, 19 mm.; tegmina, ♂, 41 mm., ♀, 51.5 mm.; hind femora, ♂, 23 mm., ♀, 30 mm.

22 ♂, 16 ♀. Grant's Pass, Oregon, Sept. 8, Morse; Gazelle, Sept. 5, Morse, Tulare, Aug. 5, Morse, Palm Springs, July 12–13, Morse, and Indio, Cal., July 9, Morse; Reno, Nev., Aug. 16; Wasatch Mts. near Beaver, July 12–18, Palmer, and Spring Lake Villa, Utah Co., Utah, Aug. 1–4, Palmer; Ft. Buchanan, south of Tucson, Ariz., Palmer;

oblong, obtusish: ligules about 7, bright yellow, 1.7 cm. long: disk-achenes obovate, upwardly hispidulous; wings very narrow; awns two, short. — Tepic, on foothills between Acaponeta and Pedro Paulo, 2 August, 1897, *Dr. J. N. Rose*, no. 1948, and by the same collector between Pedro Paulo and San Blascito, 4 August, 1897, no. 3343. Types in herb. U. S. Nat. Museum and herb. Gray.

++ ++ Rays nearly white. Florida species.

13. V. HETEROPHYLLA, Gray, l. c. 12 (1883), & Syn. Fl. i. pt. 2, 288; Chapm. Fl. S. U. S. ed. 3, 255. *Actinomeris heterophylla*, Chapm. Bot. Gaz. iii. 6. — Low pine barrens, E. Florida, *Chapman*, *Palmer*, *Curtiss*, no. 1468[a], *Garber*.

+ + Leaves rhombic or deltoid with cuneate petiolar base.

++ Leaves densely canescent-tomentose beneath.

14. V. COULTERI, Gray. Leaves rhombic-oblong, finely toothed; blade not at all hastate or deltoid. — Proc. Am. Acad. xix. 13; Hemsl. l. c. iv. 57. *V. Capitaneja*, Hemsl. l. c. ii. 187, in part, not Nees. — S. Mexico, Zimapan, *Coulter*, nos. 341, 369.

++ ++ Leaves covered with slightly scabrous subappressed pubescence, pale green on both surfaces; blade subhastate or deltoid.

15. **V. Schaffneri.** Erect 1–several-stemmed perennial, slightly ligneous at the base: leaves about 3 pairs, opposite, the blade triangular, coarsely crenate-toothed, acutish or obtuse, contracted below into cuneate broadly winged entire petioles half their length; these decurrent upon the stem in herbaceous wings: peduncles long, terminal, terete, wingless, 1–2-headed; pedicels relatively short: bracts of the involucre 2–3-seriate, oblong, obtuse, canescent-pubescent about the margins: ligules about 12, oblong, deep yellow, 1.8 cm. long: achenes obovate, 7 mm. long, glabrous; body black, lucid; wings of medium breadth, thin, translucent. — Mexico, San Luis Potosi, in sandy ground near the city, September, 1876, *Schaffner*, nos. 258, 301, in part, *Parry & Palmer*, no. 473.

Var. exalata. Winged petioles subauriculate at the base not at all decurrent. — With the type at San Luis Potosi, *Schaffner*, no. 301 in part, also in "North Mexico," *Parry* (1878), no. 26½ in part.

++ ++ ++ Leaves (yellow-green) papillose-scabrous, rhombic-ovate, shallowly serrate-dentate.

16. V. CAPITANEJA, Nees, Linnæa, xix. 729 (1847); Hemsl. l. c. 187, in part (only as to pl. Bourgeau). ? *V. crocea*, Klotzsch in Klatt, l. c. 94 (nomen subnudum). *Actinomeris pedunculosa*, DC. Prodr. v.

576. — Valley of Mexico, Santa Fé, *Bourgeau*, no. 377, Tacubaya, *Schaffner*, no. 242; Durango, *E. W. Nelson*, no. 4600, *Palmer*, no. 318 (coll. of 1896).

* * * * Peduncles long and wingless; stems also wingless throughout.

+ Species of Mexico and S. W. United States.

++ Leaves chiefly opposite, very obtuse, narrowed to a distinct although winged petiole.

17. V. LONGIPES, Hemsl. Biol. Cent.-Am. Bot. ii. 188. — Mexico without locality, *Coulter*, no. 342. To this species we should refer Pringle's no. 3215, collected on rocky hillsides, San José Pass, State of San Luis Potosi, 22 July, 1890.

++ ++ Leaves chiefly alternate, the upper lanceolate, narrowed to an obtuse apex, sessile by a somewhat contracted but auriculate-clasping base: involucral bracts narrowly oblong.

18. **V. Rothrockii.** Stems erect, herbaceous, 6 dm. high, usually simple and 1-headed, terete, puberulent, scabrous, 1 to 4 from a thickish woody stock: leaves oblong-obovate, crenate-dentate from below the middle, green and scabrous-pubescent on both sides, 5 to 8 cm. long, half as broad, amplexicaul by two broad basal auricles: peduncles long, naked, terminal, rarely branched: heads 1.5 to 2 cm. broad exclusive of rays; involucral scales about 2-seriate, not very unequal, oblong, obtuse, hirtellous to strigillose, the inner somewhat erose-dentate: rays 8 to 12, orange-yellow, 1.5 to 2 cm. long: achenes 7 mm. long, broadly winged, glabrous; pappus obsolete. — *V. Wrightii*, Gray, Proc. Am. Acad. xix. 12, in part, & Syn. Fl. i. pt. 2, 287, in part. *Actinomeris Wrightii*, Gray, Pl. Wright, ii. 89, not of Pl. Fendl.; Rothrock in Wheeler, Rep. vi. 162, t. 8; Hemsl. Biol. Cent.-Am. Bot. ii. 186, excl. pl. Texas. — S. Arizona, Camp Bowie, *Dr. J. T. Rothrock*, no. 452, Ojo de Gavilan, *Thurber*, no. 1058, foothills of the Sta. Rita Mts., *Pringle;* Arizona without locality, *Lemmon;* New Mexico, between the Copper Mines and Coude's Camp, *Wright*, no. 1235; Coahuila, *Palmer*, nos. 585, 597, 598.

We take pleasure in dedicating this species to Dr. Rothrock, who (l. c.) first noted differences between this plant and the Texan species to which it has long been referred.

++ ++ ++ Leaves subsessile by a cuneate exauriculate base; the upper oval: involucral bracts broadly oblong.

19. **V. Lindheimeri.** *V. Wrightii*, Gray, Proc. Am. Acad. xix. 12 (1883), in part, & Syn. Fl. i. pt. 2, 287, in part, not Griseb. (1866).

Actinomeris Wrightii, Gray, Pl. Fendl. 85. — Rocky places in woods, W. Texas, *Lindheimer*, nos. 37, 38, 643, *Wright*.

+ + Species of the S. E. United States.

++ Leaves coarsely serrate-dentate: rays very long.

20. V. NUDICAULIS, Gray, Proc. Am. Acad. xix. 12 (1883), & Syn. Fl. i. pt. 2, 288; Chapm. Fl. S. U. S. ed. 3, 255. *Helianthus? aristatus*, Ell. Sk. ii. 428. *Actinomeris nudicaulis*, Nutt. Trans. Am. Phil. Soc. vii. 364; Torr. & Gray, Fl. ii. 336. — Rich pine woods, Georgia, *Boykin*; Alabama, *Buckley*, *Donnell Smith*; Florida, *Chapman*, *Curtiss*, nos. 19, 5910, *Nash*, no. 2202.

++ ++ Leaves remotely serrulate or subentire: rays very short.

21. V. WAREI, Gray, ll. cc. *Actinomeris pauciflora*, Nutt. Am. Jour. Sci. v. 301, & Trans. Am. Phil. Soc. vii. 364. — Low pine barrens, W. Florida, *Ware*, *Chapman*.

§ 6. SONORICOLA. Heads large or medium-sized, seldom numerous: rays yellow, often pale; scales of the involucre narrowly to broadly oblong; awns of the pappus long and slender, at least when young much longer than the breadth of the achene: leaves opposite (at least below), ovate (lanceolate in *V. chihuahuensis*), not decurrent along the stem. Stems wingless, often ligneous. Species of the general Sonoran region forming a natural group.

* Body of the mature achenes 6 to 10 mm. long.

+ Leaves sessile.

22. V. DISSITA, Gray, Proc. Am. Acad. xx. 299. — Lower California, near Todos Santos Bay, *Orcutt*, no. 1233, and La Guilla, no. 1355.

+ + Leaves on broadly winged auriculate-clasping petioles: Lower Californian.

23. V. PALMERI, Wats. Proc. Am. Acad. xxiv. 56 (1889). — Mountain Cañons, Los Angeles Bay, Lower California, *Palmer*, no. 528.

+ + + Leaves on long narrowly winged exauriculate petioles: Mexican.

24. V. LEPTOCHÆTA, Gray, Proc. Am. Acad. xxi. 389 (1886). — S. W. Chihuahua, *Palmer*, no. 170.

* * Body of achenes 4 to 5 mm. long, glabrous; wings broad, fringed.

25. V. EROSA, Brandegee, Proc. Calif. Acad. Sci. ser. 2, iii. 146 (1891). — Sierra de San Francisquito, Lower California, *Brandegee*.

* * * Body of the achenes 3 to 5 mm. long, upwardly pubescent; wings narrower.

+ Bracts of the involucre not very unequal, 2–3-seriate, grayish green: Mexican.

26. V. CHIHUAHUENSIS, Gray, l. c. — Limestone ledges, Jimulco, Durango, and Carneros Pass, Coahuila, *Pringle*, nos. 121, 2782, and Sta. Eulalia Mts., Chihuahua, *Pringle*, no. 657; Durango, *Palmer*, no. 322 (coll. of 1896), a form with broader deltoid leaves.

+ + Bracts of the involucre strongly unequal, 4–5-seriate, at length nigrescent: Lower Californian.

29. V. VENOSA, Greene, Bull. Torr. Club, ix. 110 (1882). *V. hastata*, Kellogg, acc. to Mrs. Curran, Bull. Calif. Acad. Sci. i. 140 (1885). *Encelia cedrosensis*, Rose, Contrib. U. S. Nat. Herb. i. 17 (achenes too young to show wings). — Cedros Island, off the coast of Lower California. *Palmer*, no. 741, *Anthony*, nos. 63, 296.

§ 7. XIMENESIA, Gray. Heads large; involucral bracts narrow, herbaceous, 2–3-seriate, subequal or the outer often more elongated and foliaceous: rays showy, yellow or orange, broad, deeply 3-toothed or -lobed at the apex: mostly annuals, always more or less canescent at least on the under surface of the coarsely toothed petiolate leaves. — Syn. Fl. i. pt. 2, 288. *Ximenesia*, Cav. Ic. ii. 60, t. 178; DC. Prodr. v. 627.

* Pales very narrow, almost filiform, persistent: petioles winged: rays short: apparently perennial.

28. V. **nana**. Dwarf, canescent-pubescent, branched from near the base; branches 1 to 1.5 dm. long, procumbent: leaves chiefly opposite, oval, obtuse or obtusish, irregularly and more often obtusely dentate, 3 to 5 cm. long, nearly half as broad, narrowed below to winged petioles; these entire or bearing two to four spreading teeth near the stem: peduncles solitary, terminal upon the branches: involucral bracts oblong to lance-linear, 8 mm. long, subequal: rays deep orange, seldom over 8 or 10 mm. in length: achenes suborbicular, broadly winged, villous; wings obtuse at the summit; pappus none. — *V. encelioides*, Gray, Syn. Fl. i. pt. 2, 228, in part. *Ximenesia encelioides*, a dwarf form, Gray, Pl. Wright. i. 112. *X. encelioides*, var. *nana*, Gray, Pl. Wright. ii. 92. — S. W. Texas, Laredo, *Berlandier*, nos. 1474, 214, *Wright*, coll. of 1851, Limpia, *Sutton Hayes*, no. 463; Coahuila, La Ventura, *E. W. Nelson*, no. 3918.

There has been an unfortunate confusion in the labelling or mounting of Wright's no. 1407, cited by Dr. Gray as the type of his var. *nana*. The plant mounted with the label no. 1407 (which shows evidences of erasure and change) is *V. encelioides*, var. *cana*, while the plant which Dr. Gray really described is undoubtedly the one here taken as *V. nana*.

* * Pales linear-oblong, entire or 2–3-toothed: annuals.

+- Achenes broadly winged from the summit to the base.

29. V. ENCELIOIDES, Benth. & Hook. f. Leaves appressed-pubescent but green above; petioles (at least of the upper leaves) provided on each side with a wing which broadens towards the base into a semi-ovate incised stem-clasping auricle: outer involucral scales long, green, much surpassing the disk: wings of the achene rather broad, acutish at the apex. — Benth. & Hook. f. acc. to Gray, Bot. Calif. i. 350; Gray, Syn. Fl. i. pt. 2, 288, in part. *Ximenesia encelioides*, Cav. l. c.; DC. l. c. — Florida, *Curtiss*, nos. 1503, 5650, *Palmer*, no. 291; Texas, *Heller*, no. 1785; Mexico, San Luis Potosi, *Parry & Palmer*, no. 468, State of Tamaulipas, Victoria, *E. W. Nelson*, no. 4425; Cuba, *Wright*, no. 3611. Naturalized in the warm parts of the Old World and cultivated in a broad-leaved form (*Ximenesia encelioides*, var. *hortensis*, DC. l. c.).

Var. cana. More canescent throughout, even the upper surface of the leaves usually whitish with copious appressed pubescence: involucral bracts shorter, subequal. — *Ximenesia encelioides*, var. δ *cana*, DC. l. c.; Gray, Pl. Wright. ii. 92. — Texas, Laredo, *Berlandier*, nos. 2068, 2074; S. W. Texas, *Wright*, no. 352, *Palmer*, no. 617; New Mexico, *Fendler*, no. 421; Cuba, *Combs*, no. 577; Hawaiian Isls., *Hillebrand*.

Var. exauriculata. Pale green annual: petioles entirely naked and slender or rarely the upper bearing a divaricate usually oblong subentire lobe on each side of the base: scales of the involucre subequal, scarcely or not at all surpassing the disk: wings of the achene broad, corky, obtuse at the apex. — *V. encelioides*, Gray, Syn. Fl. i. pt. 2, 288, in part; Hemsl. l. c. *Ximenesia encelioides*, Rothrock in Wheeler, Rep. vi. 163. — Kansas, *Hitchcock*, no. 277; Colorado, in the Arkansas Valley near Pueblo, *Greene*, Colorado Springs, *Miss Mulford;* Arizona, on the Little Colorado, *Sitgreaves Exp.*, *Thurber*, no. 667, *Rothrock*, no. 772, *Pringle;* Mexico, Coahuila, *Palmer*, no. 2064, Sonora, *Hartman*, no. 229, without locality, *Rose*, no. 3076.

+- +- Achenes narrowly winged or only winged near the summit.

30. V. AUSTRALIS, Baker in Mart. Fl. Bras. vi. pt. 3, 215. *Ximenesia microptera*, DC. l. c.; Hook. & Arn. in Hook. Jour. Bot. iii. 316; Griseb. Symb. Fl. Argent. 195. *X. australis*, Hook. & Arn. in DC. l. c. vii. 291. — South America, Buenos Ayres, *Bacle;* Concepcion del Uruguay, *Lorentz;* Central Paraguay, *Morong*, no. 98; Bolivian Plateau, *Bang*, no. 1003; also N. E. Mexico at Matamoras, *Berlandier*, no. 2286. From description we cannot separate *V. aurita*, Philippi, Ann. del. Mus. Nat. Chile, Bot. 1891, p. 48.

§ 8. VERBESINARIA, DC. Heads mostly numerous, medium-sized or large; involucral bracts lanceolate to linear-oblong: rays relatively long (1 to 2.5 cm.) and showy, yellow: leaves linear- to lance-oblong, or ovate, alternate (except in *V. hypoglauca*, *V. sororia*, *V. occidentalis*, and *V. elegans*), never lobed. — Prodr. v. 612, in part.

* Leaves narrow, linear to oblong, entire or remotely serrulate.

+ Outer bracts of the involucre of irregular length, some of them elongated and much surpassing the disk: stem wingless: leaves 1 to 2 dm. long.

31. V. LONGIFOLIA, Gray, Proc. Am. Acad. xix. 12 (1883), & Syn. Fl. i. pt. 2, 287. *Actinomeris longifolia*, Gray, Pl. Wright. ii. 89; Hemsl. Biol. Cent.-Am. Bot. ii. 185. — Mountains east of Santa Cruz, Sonora, *Wright*, no. 1234; Arizona, *Rothrock*, no. 608, *Pringle*, no. 327, *Lemmon;* Chihuahua, *Pringle*, no. 1286.

+ + Outer bracts of the involucre not surpassing the inner nor the disk.

++ Leaves soft-pubescent or tomentose beneath.

32. **V. hypomalaca.** Erect perennial herb, 4 to 6 dm. high: stems single or several, virgate, simple, terete, pubescent to hirsute, very leafy: leaves narrowly oblong to linear, obtuse or acute, obsoletely crenulate or serrulate (the margins tending to be revolute), 3 to 8 cm. long, 4 to 10 mm. broad, sessile by a cordate-auriculate base, pubescent and very scabrous above, canescent-tomentose beneath: heads 6 to 30, ovate or at length subconical, 1 cm. in diameter excluding the rays, borne on erect pubescent pedicels in a flat-topped corymb: involucral scales about 2-seriate, linear-oblong, obtusish, pubescent: ligules 15, about 1 cm. long. — *V. stricta*, Gray, Proc. Am. Acad. xix. 13, in part, & xxii. 427. *Actinomeris stricta*, Hemsl. l. c. 186, in part. — Orizaba, *Botteri*, no. 95, *Seaton*, no. 367; Rio Blanco, Jalisco, *Palmer*, no. 163; Cerro Ventoso above Pachua, Hidalgo, *Pringle*, no. 7611; Coahuila, *Palmer*, nos. 627, 628; Mexico without locality, *Coulter*, no. 362.

Var. hypochlora. Leaves yellowish green and soft-pubescent rather than tomentose beneath. — Hills of Patzcuaro, Michoacan, *Pringle*, no. 4136; near Monte Escobedo, Zacatecas, *Dr. J. N. Rose*, no. 2630. Types in herb. Gray and herb. U. S. Nat. Museum.

++ ++ Leaves glabrous or covered with a short sparse and scabrous pubescence beneath.

= Stem wingless: rays deep yellow.

33. V. STRICTA, Gray, l. c. xix. 13, in part. *Actinomeris stricta*, Hemsl. l. c. as to first named type. — San Luis Potosi, *Parry & Palmer*,

no. 461, *Schaffner*, no. 343; Durango, *Palmer*, no. 453, *E. W. Nelson*, no. 4564; Chihuahua, *Pringle*, nos. 1151, 1285; near Sta. Teresa, Tepic, *Rose*, no. 3397. This species differs from the preceding in its broader (oblong) less crowded leaves very different in pubescence and tending to be conduplicate along the midnerve. The range is also quite different.

= = Stems narrowly winged: rays pale yellow.

34. V. STENOPHYLLA, Greenm. Proc. Am. Acad. xxxii. 309. — Moist slopes above Cuernavaca, Morelos, altitude 2,000 m., *Pringle*, nos. 6503, 6668.

* * Leaves broader, lanceolate to ovate.

+ Leaves coarsely dentate: Mexican.

++ Leaves, at least in part, decurrent upon the stem.

35. V. COAHUILENSIS, Gray, l. c. 14; Hemsl. l. c. iv. 57. — Coahuila. 9.5 km. east of Saltillo, *Palmer*, nos. 584, 619; Nuevo Leon, mountains about Monterey, *Pringle*, no. 2870.

Var. viridior. Lower surface of the leaves green, scabrous-puberulent instead of canescent-tomentose as in the typical form. — Limestone ledges, Carneros Pass, Coahuila, 12 August, 20 September, 1890, *Pringle*, no. 3268. Type in herb. Gray.

++ ++ Leaves sessile and auricled, but never decurrent.

36. V. HYPOLEUCA, Gray, l. c. xv. 37, xix. 13; Hemsl. l. c. ii. 188. — San Luis Potosi, Mexico, *Parry & Palmer*, no. 474, *Schaffner*, no. 300.

+ + Leaves serrate or entire (serrate to coarsely dentate in the S. American *V. subcordata*).

++ Perennial herbs or shrubs, with solitary heads and wingless stems: S. American.

= Achenes narrowly winged.

37*. V. ARNOTTII, Baker, l. c. 215. *V. helianthoides*, Hook. & Arn. in Hook. Jour. Bot. iii. 316, not Michx. *V. Hookerii*, Klatt, l. c. xx. 92. — Paraguay at Asuncion, *Gilbert*, no. 1043: Argentine Republic, Entre Rios, *Tweedie*.

= = Achenes broadly winged.

a. Leaves opposite.

38*. V. ASPILIOIDES, Griseb. Symb. Fl. Argent. 194. — Argentine Republic in Prov. Cordoba.

b. Leaves all alternate.

39*. V. VIGUIEROIDES, Baker, l. c. — Paraguay at Caaguasu, *Balansa*, no. 852a.

++ ++ Stems wingless: heads corymbose: South American shrubs.

= Scales of the involucre short, obtuse or obtusish, very unequal: leaves slender-petioled, not at all auricled.

40. V. GLABRATA, Hook. & Arn. in Hook. Jour. Bot. iii. 315; Baker l. c. 211. *V. helianthoides*, Gardn. in Hook. Lond. Jour. Bot. vii. 424, acc. to Baker, l. c. — Common in the woods of E. Brazil, *Martius*, no. 821, *Burchell*, no. 4593, *Sello*, nos. 863, 864, 1100, 1101.

= = Scales of the involucre about 2-seriate, not very unequal, obtuse to acute, canescent-tomentulose: wings of the achenes very narrow: petioles very short, narrowly wing-margined and subauriculate at the base or none; leaves canescent-tomentose beneath.

a. Andean.

41. V. ELEGANS, HBK. Nov. Gen. & Spec. iv. 204; Klatt, Leopoldina, xx. 93. — Andes of Ecuador, *Humboldt* & *Bonpland*, *Jameson*, *Couthouy*.

b. E. South American.

42. V. SUBCORDATA, DC. Prodr. v. 614 (where described as a shrub); ? Baker l. c. 213 (where described as a perennial herb). ? *V. auriculata*, Hook. & Arn. in Hook. Jour. Bot. iii. 315, not DC. — Uruguay and Argentine Republic.

= = = Scales of the involucre caudate-attenuate, very unequal, gray-villous: leaves sessile, subauriculate at the base.

43. **V. Mandonii**, SCH. BIP. in herb. Grayish-pubescent shrub with terete wingless branches: leaves alternate, ovate-lanceolate to lanceolate, acuminate to attenuate, subentire or repandly few-toothed, finely appressed-pubescent and somewhat scabrous above, soft-pubescent and paler but green beneath, pinnately veined, 6 to 15 cm. long, 1.5 to 3 cm. wide, narrowed (gradually or more abruptly) to a sessile sub-biauriculate base; the auricles slightly decurrent and tending to persist upon the stem after the fall of the leaf: corymbs about 12-headed, flat-topped, villous to tomentose; involucral scales 3–4-seriate, linear, acute to attenuate: rays about 14, oblong, light yellow, 1.2 cm. long, 4 mm. wide: achenes of the disk-flowers oblanceolate, attenuate at the base, narrowly and equally winged on both sides above, the wings extending upward on

the two short awns. — Linnæa, xxxiv. 528 (nomen nudum), & Bull. Soc. Bot. France, xii. 79 (nomen nudum); Britton, Bull. Torr. Club, xix. 150 (nomen subnudum); Rusby, Mem. Torr. Club, iii. no. 3, 60 (nomen nudum). — Andes of Bolivia, in woods, La Paz, altitude 2,600 to 3,700 m., January, 1861, *G. Mandon*, no. 57 in herb. Gray; October, 1895, *Rusby*, no. 1721; 1889, *Bang*, no. 4.

↔ ↔ ↔ Stem wingless: leaves opposite at least below: heads corymbose: Mexican species.

= Leaves large, gray-pubescent beneath: achenes with broad fimbriate wings.

44. V. SORORIA, Gray, Proc. Am. Acad. xv. 37; Hemsl. l. c. 190. — San Luis Potosi, *Parry & Palmer*, no. 466.

= = Leaves smaller, lanceolate, white beneath: achenes very narrowly winged.

45. V. HYPOGLAUCA, Sch. Bip. An attractive shrub, 3 to 5 m. high, with habit of the following species. — Sch. Bip. in Klatt, Leopoldina, xxiii. 144 (1887). — S. Mexico, Cumbre de Acalcingo, *Liebmann*, no. 485; Oaxaca on the Sierra de San Felipe, altitude 3,000 m., *Pringle*, no. 6041.

↔ ↔ ↔ ↔ Stem (at least on the upper part of the internode) bearing narrow, soon corky wings: leaves alternate: achenes very narrowly margined: fruticose. S. Mexican species.

= Leaves whitened beneath by an extremely fine and close pubescence: pedicels short, glabrous.

46. V. NERIIFOLIA, Hemsl. l. c. 188. — Chiapas, *Ghiesbreght*, no. 528, *Nelson*, no. 3466. Type number in herb. Gray.

= = Leaves loosely canescent-tomentose beneath: pedicels longer and more slender, pubescent with spreading hairs.

47. V. OAXACANA, DC. Prodr. v. 614, not Klatt, l. c. xxiii. 144. — Mountains of Oaxaca, *Andrieux*, no. 301, acc. to DC. l. c. To this species may be referred L. C. Smith's nos. 877 and 895, coll. at San Juan del Estado at 1,800 m. altitude.

= = = Leaves slightly paler but green beneath: pedicels puberulent to tomentulose.

48. V. LIEBMANNII, Sch. Bip. in Klatt, l. c. xxiii. 144 (1887). *V. variabilis*, Rob. & Greenm. Proc. Am. Acad. xxxii. 47 (1896). — S. Mexico, Cumbre de Estepa, *Liebmann*, no. 538; mountains of Oaxaca, *E. W. Nelson*, no. 1393, *Pringle*, no. 4918, *Conzatti*, no. 31; and a doubtful specimen from Guerrero, *E. W. Nelson*, no. 2215.

++ ++ ++ ++ ++ Stem mostly provided with narrow or broad herbaceous wings: tall herbaceous species of the United States.

= Wings of the achene very narrow or obsolete: leaves ovate, opposite: heads rather small and few-flowered.

49. V. OCCIDENTALIS, Walt. Fl. Car. 213 (1788); Gray, Syn. Fl. i. pt. 2, 287, q. v. for rather extensive synonymy. — Woods, etc., Pennsylvania to Florida "and Illinois" (doubted).

= = Wings of the achene broad: leaves chiefly alternate: heads rather large, numerously flowered: rays long.

50. V. HELIANTHOIDES, Michx. Fl. ii. 135; Gray, Syn. Fl. i. pt. 2, 288. *Actinomeris helianthoides*, Nutt. Gen. ii. 181; DC. Prodr. v. 575, vii. 290, incl. formal vars. *Nuttallii* and *Elliottii*. ?*A. oppositifolia*, DC. l. c. vii. 290 (opposite-leaved form). — Open woods, etc., Ohio to Iowa, Georgia, and Texas; common.

§ 9. SAUBINETIA (*Saubinetia*, Remy in Gay, Fl. Chil. iv. 284, extended). Heads as in the last or smaller: rays present, yellow (rather pale in *V. boliviana*, of uncertain color in *V. guatemalensis*), short, little exserted: leaves oblong or ovate to lanceolate, not lobed (except sometimes in *V. boliviana*).

* Stem wingless: leaves sessile and biauriculate or borne on winged biauriculate petioles; auricles (narrow and sometimes obscure in *V. oreopola*) herbaceous, continuous with the blade, neither deciduous nor decurrent.

+ Leaves ovate or ovate-lanceolate, narrowed to winged auriculate petioles: S. American.

51. V. BOLIVIANA, Klatt, Ann. Naturh. Hofmus. Wien, ix. 361 (1894). *V. Bridgesii*, Rusby, Mem. Torr. Club, iv. 212 (1895). — Andes of Bolivia, *Cuming*, near Cochabamba, *Bang*, no. 974. Rays pale yellow.

+ + Leaves oblong, sessile, more or less auriculate or amplexicaul: Mexican.

++ Leaves green and glabrous beneath.

52. V. NELSONII, Rob. & Greenm. Proc. Am. Acad. xxxii. 46. — Mountains of Guerrero between Ayusinapa and Petatlan, altitude 1,500 to 2,100 m., 14 December, 1894, *E. W. Nelson*, no. 2118. Types in herb. Gray and herb. U. S. Nat. Museum.

++ ++ Leaves pubescent to canescent-tomentose beneath.

= Involucral scales lanceolate, acuminate.

53. V. POTOSINA, Rob. Proc. Am. Acad. xxvii. 175. — San Luis Potosi, mesas at Hacienda de Angostura, *Pringle*, no. 5113.

= = Involucral scales oblong, obtusish.

a. Rays 7 to 8 mm. long.

54. **V. oreopola.** Shrub with short internodes and pale buff cortex: branchlets pubescent with fine white soft sub-appressed hairs: leaves narrowly lance-oblong, subentire or remotely serrulate, attenuate at the apex, narrowed to a sessile somewhat biauriculate base, green, puberulent, and slightly scabrous above, canescent-tomentose or merely pubescent and scarcely paler beneath, 5 to 15 cm. long, 1 to 2.5 cm. broad: heads (7 to 10 mm. in diameter exclusive of rays) 14 to 20 in a compound flat-topped corymb: rays 10 to 12, oblong, yellow: bracts of the inflorescence linear-oblong, acute; involucral scales oblong, obtusish, soft-pubescent and ciliate; chaff stramineous, abruptly contracted to a straight erect mucro: body of the achene black, puberulent, obovate; wings relatively broad, divergent at the summit; awns of the pappus 2, slender, two thirds as long as the body of the achene. — Collected in mountains about San Luis Potosi, August, 1876, *Schaffner*, no. 344; *Parry & Palmer*, no. 457 (1878). Incorrectly referred to *V. persicifolia* and *V. salicifolia* (= *V. virgata*).

b. Rays broadly oblong, 3-dentate, 3 mm. long.

55. **V. guatemalensis.** Stems striate, wingless, alternately branched, sparingly pubescent: leaves alternate, lance-oblong, acute, subentire, glabrate and bullate above, somewhat paler and canescent with fine close appressed pubescence beneath, 7 to 10 cm. long, 1 to 2 cm. broad, narrowed below to a biauriculate subamplexicaul base, not decurrent upon the stem: inflorescence at first loosely but above fastigiately much-branched, sordid-pubescent: heads numerous, in fruit 7 to 9 mm. in diameter: rays very short, 3-dentate, little exserted, probably yellow: achenes obovate, broadly and equally winged; wings rounded at the apex; body 5 mm. long, tuberculate especially along the prominent midnerve: pappus-awns 2, long, slender, equal. — *V. virginica*, Coulter in Donnell Smith, Enum. Pl. Guat. pt. 4, 88, not L. — Palin, Depart. Amatitlan, Guatemala, altitude 1,100 m., February, 1892, *J. Donnell Smith*, no. 2860.

* * Leaves more or less decurrent upon the stem.

+ Involucral scales narrow, linear: pales villous near the summit.

++ Leaves sparsely pubescent or at length glabrate beneath: Central American.

56. V. PALLENS, Benth. in Oersted, Vidensk. Meddel. 1852, p. 97; Hemsl. l. c. 189. — Nicaragua, on the western slopes of the volcano El Viejo, *Oersted*.

++ ++ Leaves permanently sordid-tomentose beneath: Bolivian.

57. **V. Soratæ**, Sch. Bip. ined. Branches terete, pubescent, narrowly and irregularly winged by the decurrent bases of the winged petioles: leaves alternate, ovate, acuminate, crenate-serrulate, rugose, scabrous-tomentose above, paler and soft sordid-tomentose beneath, 6 to 10 cm. long, 2.5 to 5 cm. broad, pinnately veined, rather abruptly narrowed to a winged and somewhat crisped petiolar portion (1 to 2.5 cm. long): corymbs much branched; branches and pedicels covered with loose sordid woolly pubescence; involucre campanulate, 7 mm. in diameter: rays about 10, oblong, pale yellow?, 7 mm. long: achenes of the disk-flowers (immature) linear, attenuate below; pappus of 2 unequal slender awns. — Linnæa, xxxiv. 528, & Bull. Soc. Bot. France, xii. 79; Britton, Bull. Torr. Club, xix. 150 (all mere mentions). — Sorata, Bolivia, *Mandon*, no. 55, and in the same locality at 2,400 m. altitude, February, 1886, *Dr. H. H. Rusby*, no. 1722.

+ + Involucral scales obovate-oblong, rounded at the apex: pales villous at the summit: Chilian.

58. V. Saubinetia, Klatt, l. c. xx. 92. *Saubinetia helianthoides*, Remy in Gay Fl. Chil. iv. 284, t. 49. — Near Coquimbo, Chili.

+ + + Involucral scales broad, ovate: pales glabrous or nearly so.

++ Involucral scales acute: leaves acuminate, tomentulose beneath, alternate.

59. **V. acapulcensis.** Stem tomentulose, partially winged by the cuneate decurrent herbaceous bases of the leaves: leaves alternate, ovate, cuspidate-denticulate, acuminate at each end, green, scabrous, and lepidote above, paler and sordid-tomentulose beneath, 1 to 1.8 dm. long, 2.5 to 7.5 cm. broad, pinnately veined; petioles relatively short, winged; heads 35 to 40, short-pedicelled in a rather dense leafless corymb, subglobose, 1.2 to 1.8 cm. in diameter; involucral bracts 2-seriate, ovate, acute, scarcely herbaceous, somewhat stramineous, striate, ciliate: rays about 10, oblong, scarcely exserted: achenes of the disk-flowers about 4 mm. long, narrowly to rather broadly winged, often tuberculate above; awns subequal. — Vicinity of Acapulco, Mexico, *Dr. Edward Palmer*, no. 162 (coll. of 1894–1895). Type in herb. Gray.

++ ++ Involucral scales obtuse: leaves obtuse, barely puberulent beneath, opposite, the uppermost alternate.

60. **V. xanthochlora.** Herbage yellowish green: stem canescent-puberulent, narrowly winged by the green decurrent bases of the leaves; these mostly opposite, ovate-oblong, obtuse, subentire or denticulate, green and concolorous on both sides, appressed-puberulent under a lens:

heads 1 to 1.5 cm. in diameter, subglobose, very short-pedicelled in a loose leafy corymb; pedicels canescent-tomentose; scales of the involucre herbaceous, suborbicular, obtuse or rounded at the apex, tomentulose: ligules about 10, bright yellow, oblong, little exserted: achenes of the disk-flowers oblanceolate, attenuate below, narrowly winged, 6 mm. long, tipped with 2 (to 3) short subequal awns. — Atlixco, Puebla, Mexico, *E. W. Nelson*, 25 July to 1 August, 1893, without number. Type in herb. Gray and herb. U. S. Nat. Museum.

* * * Leaves (silky-tomentose beneath) not decurrent, but stem with herbaceous wings.

61. V. MOLLIS, HBK. Nov. Gen. & Spec. iv. 203; DC. Prodr. v. 617; Hemsl. l. c. 188; Klatt, l. c. xx. 94 (where identity of *V. sericea* is suggested). *V. sericea*, Kunth & Bouché, Ind. Sem. Hort. Berol. 1848, 14; Walp. Ann. ii. 867; Hemsl. l. c. 190. — S. Mexico, originally coll. between Guanajuato and Villalpando by *Humboldt & Bonpland*, mountains of Oaxaca, *Galeotti*, no. 2002, *Pringle*, no. 4863, *E. W. Nelson*, no. 1782, *Conzatti & González*, no. 400.

* * * * Leaves tomentulose beneath, bearing at the base of the short petiole one or two small thickish auricles which soon become corky and fall off: stem wingless: tips of the pales straight.

62. V. ONCOPHORA, Robinson & Seaton, Proc. Am. Acad. xxviii. 109. *V. virgata*, var.? *conyzoides*, DC. Prodr. v. 616; A. DC. Calques des Dess. t. 596. *V. conyzoides*, [Moc. & Sess. acc. to] DC. l. c. (1837), not Trew (1769). — State of Mexico, *Bourgeau*, no. 967, *Pringle*, no. 4310.

* * * * * Leaves smoothish beneath: stem usually provided with narrow soon corky wings or ridges more or less decurrent from the short petioles: tips of the pales recurved.

63. V. VIRGATA, Cav. Shrub 1 to 3 m. high. — Ic. iii. 38, t. 275. *V. salicifolia*, HBK. l. c. 205, although described as herbaceous, is with scarcely a doubt a synonym, as suggested by Hemsl. Biol. Cent.-Am. Bot. ii. 190. *V. persicifolia*, Klatt, Leopoldina, xx. 93, not DC. — Valley of Mexico, *Bourgeau*, no. 963, *Schmitz*, no. 52, *Schaffner*, no. 6; mountains of Oaxaca, *Pringle*, no. 4946, *E. W. Nelson*, no. 1380, *Conzatti*, no. 714; near Plateado, Zacatecas, *Rose*, no. 2753.

* * * * * * Leaves not auricled at the base: stem not winged.

+– Leaves opposite, coarsely dentate.

64. V. SERRATA, Cav. Leaves ovate, finely pubescent above, cinereous-pubescent beneath: pales shorter than or not greatly exceeding the

achenes. — Ic. iii. 7, t. 214; DC. l. c. 613; Hemsl. l. c. 190; Klatt, l. c. 92, but "angustissime alatis" can apply only to the very young achenes. — Mexico, Guanajuato, *Humboldt & Bonpland*, *Dugès*, no. 469; Aguas Calientes, *Hartweg*, no. 115; Michoacan, *Pringle*, no. 4114; Hidalgo, *Pringle*, no. 6537; Monte de San Juan del Rio, *Berlandier*, no. 1289.

Var. Pringlei. Leaves ovate-oblong, coarsely and irregularly serrate, papillose-scabrous above, pubescent and subcinereous beneath: pales long, recurved, considerably exceeding the mature achenes. — *V. Pringlei*, Robinson, Proc. Am. Acad. xxvii. 175. — Barrancas near Guadalajara, Jalisco, *Pringle*, no. 3845.

Var. amphichlora. Leaves lance-ovate, finely appressed-pubescent and bright green upon both surfaces. — Collected between Ramos and Inde, Durango, Mexico, *E. W. Nelson*, 11–14 August, 1898, no. 4680. Types in herb. Gray and herb. U. S. Nat. Museum.

+ + Leaves opposite, serrulate.

++ Leaves green and sparingly pubescent beneath: involucral scales obtuse.

65. V. RESINOSA, Klatt, Leopoldina, xxiii. 144. — S. Mexico, Yavesia, *Liebmann*, no. 331. Type in herb. Bot. Gard. Copenhagen; fragments and a good sketch in herb. Gray.

++ ++ Leaves pale, tomentulose, and prominently reticulated beneath: involucral scales acute.

66. V. GRAYI, Benth. & Hook. f. acc. to Hemsl. l. c. 188. *Zexmenia Grayii*, Sch. Bip. in Seem. Bot. Herald, 305. — North Mexico, Sierra Madre, *Seemann*, no. 2004.

++ ++ ++ Leaves canescent-tomentose beneath without prominent reticulation: involucral scales acute to acuminate.

67. **V. molinaria.** Branches terete, canescent with an almost microscopic appressed pubescence: leaves opposite, oblong-lanceolate, acuminate at each end, serrulate, pinnately veined, pale green and slightly scabrous-puberulent above, canescent and silky-tomentose beneath, 1.2 to 1.4 dm. long, 3 to 3.7 cm. broad; petioles 7 mm. long: heads corymbose, 8 to 10 mm. in diameter; involucral scales about 2-seriate, oblong, acute: rays about 6, oblong, yellow, 4 mm. long, half as broad; the tubular portion pubescent: pales oblong, subtruncate, apiculate: achenes of the disk-flowers 2 to 3 mm. long, puberulent, moderately winged on both edges: pappus of two short awns. — *V. oncophora ?* Greenm. Proc. Am. Acad. xxxii. 309. — Under bluffs of a barranca above Cuernavaca, Morelos, altitude 2,000 m., 1 November, 1896, *C. G. Pringle*, no. 6600. The specific name is suggested by its dusty appearance. Type in herb. Gray.

+ + + Leaves alternate or scattered.

++ Fruiting heads about 1 to 1.5 cm. in diameter.

= Leaves not lepidote above.

a. Scales of the involucre 8 to 10 mm. long: achene with a single small earlike wing in the manner of *Otopappus*, or with two very unequal wings: Mexican.

68. V. **Robinsonii**, Fernald in herb. *Otopappus alternifolius*, Robinson, Proc. Am. Acad. xxvi. 165 (1891); *O. Robinsonii*, Klatt, Ann. Naturh. Hofmus. Wien, ix. 362 (1894).— Limestone hills, San José Pass, San Luis Potosi, *Pringle*, no. 3310. While this species possesses the typical pappus of *Otopappus*, its habit, and as we now believe its genetic relationship, are nearer to *Verbesina*. The original specific name, *alternifolius*, being preoccupied under *Verbesina*, the species is transferred under the next name. To this species may be referred, with some doubt, *V. Humboldtii*, Klatt, Leopoldina, xx. 92 (as to pl. Mex.), not Spreng. *V. Humboldtii*, Spreng. (*V. helianthoides*, HBK. Nov. Gen. & Spec. iv. 204), is supposed to be Ecuadorian and is described by Kunth as having leaves glabrous above, which is not the case here.

b. Scales of the involucre about 1 cm. long: Bolivian.

69. V. cinerea, Rusby, Mem. Torr. Club, vi. 63. — Near Cochabamba, Bolivia, *Bang*, no. 1092.

c. Scales of the involucre about 7 mm. long: E. South American.

70. V. sordescens, DC. Prodr. v. 613; Baker in Mart. Fl. Bras. vi. pt. 3, 214, and var. *semiserrata* (=*V. semiserrata*, Sch. Bip. in herb. acc. to) Baker, l. c. — Brazil, *Riedel*, and others; Central Paraguay, *Morong*, no. 628a.

d. Scales of the involucre 4 to 6 mm. long: wings of the achenes usually subequal: leaves serrate or serrulate: Mexican.

1. Leaves green and closely appressed-puberulent (not scabrous) beneath.

71. V. **chiapensis**. Branchlets striate, appressed-puberulent, at length glabrate and smooth; internodes rather long: leaves lance-oblong, mucronulate-serrulate, attenuate at each end, subglabrous above, scarcely paler and finely appressed-puberulent beneath, pinnately veined, becoming 2 dm. long, 6 cm. broad: corymb 20–30-headed, 1.5 dm. broad; heads 1.2 cm. in diameter excluding the linear-oblong spreading deep yellow rays (8 mm. in length); pedicels slender, 1 to 4 cm. long, covered with short but copious somewhat spreading pubescence; scales of the involucre sub-uniseriate, ovate-oblong, acutish, 3 to 4 mm. long, much

exceeded by the flowers of the at length subglobose disk: achenes (young) obovate, 2 mm. long, puberulent; wings equal but ear-like, confined to the upper part of the achene and more or less adnate to the two pappus awns, these nearly as long as the body of the achene. — Chiapas, Mexico. near Tumbala, altitude 1,200 to 1,700 m., *E. W. Nelson*, no. 3364. Types in herb. Gray and herb. U. S. Nat. Museum.

2. Leaves grayish-tomentulose (not scabrous) beneath: pedicels slender: Mexican.

72. **V. cinerascens.** Branches downy with soft spreading pubescence, terete, pithy: leaves alternate, lance-oblong, attenuate at both ends, remotely serrate, puberulent and scabrous above, grayish-tomentulose beneath, pinnately veined, 1 to 1.3 dm. long, 3 cm. broad: corymbs compound, fastigiate, about 40-headed; pedicels tomentulose, 3 cm. long, erect, the middle one abbreviated; ovate-oblong involucral scales acutish, pubescent, 4 mm. long: flowers pale yellow: rays about 10, narrowly oblong, 8 mm. in length: achenes of the disk-flowers narrowly and somewhat unequally winged; the body 2.5 mm. long, upwardly puberulent. — On cool wooded slopes of a barranca near Guadalajara, Jalisco, 20 November, 1888, *C. G. Pringle*, no. 1806 (distributed as *V. salicifolia*). Type in herb. Gray.

3. Leaves tomentulose at least on the veins beneath, green and at length decidedly scabrous on both surfaces: scales of involucre broadly ovate; pedicels short and thick.

73. **V. crassipes.** Shrub with terete wingless dark purple scabrous-tomentose branches: leaves alternate, obovate-lanceolate, serrate, acute, sessile by a cuneate neither auriculate nor decurrent base, papillose and very scabrous above, green, tomentulose (at least on the nerves and pinnate veins) and at length scabrous beneath, 6 to 9 cm. long, a third as broad, the margins tending to be revolute: corymbs dense, many-headed; pedicels thick, mostly very short: fruiting heads depressed-globose, 1.5 cm. in diameter: involucral scales ovate-oblong to obovate, finely appressed-pubescent, the outer obtuse, thickened below, the inner acute, somewhat stramineous; pales broad, ovate, acute, stramineous, somewhat ciliate above: rays about 10, linear-oblong, 8 to 9 mm. long: achenes of the disk-flowers, 3 to 4 mm. long, oblong, narrowly and subequally winged; awns 2, slender, subequal. — Oaxaca, Cañada Sta. Maria, 8 December, 1895, *C. & E. Seler*, no. 1476, also by the same collectors in the district of Nochistlan, 14 December, 1895, no. 1590. Types in herb. Gray and herb. Berlin Museum.

4. Leaves white and silvery beneath with appressed microscopic hairs.

74. **V. hypargyrea.** Shrub or tree with leafy, at first cinereous-puberulent, at length glabrate and warty branches: leaves (smaller than in the related species) lanceolate, attenuate at each end, serrate, conspicuously discolorous, green and microscopically puberulent above, silvery-white beneath, pinnately veined, with somewhat prominent reticulation beneath, 8 to 11 cm. long, 1.5 to 2 cm. broad: heads subglobose, numerous, in compound corymbs; pedicels cinereous-puberulent, 6 to 12 mm. long; pales stramineous, tipped by an erect mucro: achenes of the disk-flowers 2 mm. long, glabrous, narrowly and about equally winged, the wings continuous upon the subequal pappus-awns. — Chiapas, between Hacienda Juncana and San Vicente, altitude 1,300 to 1,800 m., 12 December, 1895, *E. W. Nelson*, no. 3510.

e. Inner scales of the involucre about 5 mm. long: leaves coarsely dentate: S. American.

75. V.? DENTATA, HBK. Nov. Gen. & Spec. iv. 205. *Pallasia dentata*, H. & B. Pl. Æq. ii. 101, t. 111. — Ecuador, between Penipe and Rio Bamba, *Humboldt* & *Bonpland;* Ecuadorian Andes, *Spruce*, no. 5792. The achenes of this species seem to be somewhat 4-angled, and the pappus-awns are very unequal.

= = Leaves (at least in age) distinctly lepidote-maculate above with round white dots (bases of fallen trichomes).

a. Lower surface of the leaves sordid-pubescent: involucre campanulate: wings of the achene broad, equal.

76. V. DONNELL-SMITHII, Coulter, Bot. Gaz. xx. 50, & in Donnell Smith, Enum. Pl. Guat. pt. 4, 88. *Encelia pleistocephala*, J. Donnell Smith, Bot. Gaz. xiii. 189, & Enum. Pl. Guat. pt. 1, 22. — Guatemala, Coban, Depart. Alta Verapaz, altitude 1,300 m., *von Tuerckheim*, no. 1121 of Mr. J. Donnell Smith's sets; San Miguel Uspantán, Depart. Quiché, altitude 1,800 m., *Heyde* & *Lux*, no. 3385 of Mr. J. Donnell Smith's sets. Type number in herb. Gray.

b. Lower surface of the leaves essentially glabrous from the first: involucre soon saucer-shaped or reflexed.

77. V. PERSICIFOLIA, DC. l. c. 614; Gray, Proc. Am. Acad. v. 183 (*persicæfolia*); Hemsl. l. c. 189; ? Klatt, l. c. xxiii. 144, but not of Klatt, l. c. xx. 93, which is *V. virgata*, Cav. — Between Santander and Victoria, N. E. Mexico, *Berlandier*, nos. 2209, 789, San Luis Potosi, *Pringle*, no. 3078; Wartenberg. Huasteca, *Ervendberg*, nos. 84, 91.

c. Lower surface of the leaves sordid-pubescent on the veins beneath: involucre saucer-shaped or at length reflexed by the enlargement of the globose head: W. Indian.

78. V. LEPROSA, Klatt, Leopoldina, xx. 93. — Morne Rouge, Martinique, *Hahn*, no. 1214.

d. Lower surface of the leaves tawny-tomentose: involucre as in the preceding: wings of the achenes variable in the same head and often very unequal and adnate to the pappus-awn in manner of *Otopappus*: Mexican.

79. V. OLIVACEA, Klatt, l. c. 93. *V. oaxacana*, Klatt, l. c. xxiii. 144, not DC. *Otopappus olivaceus*, and *O. oaxacanus*, Klatt, Ann. Naturh. Hofmus. Wien, ix. 362. — S. Mexico, Hacienda de la Laguna, *Schiede*, no. 340; Mirador, at Consaquitla, *Liebmann*, no. 540 (*V. leprosa*, Klatt, Leopoldina, xxiii. 143, not l. c. xx. 93; also the undescribed *V. Sartorii*, Sch. Bip. acc. to Klatt, l. c. xxiii. 143), and at Trapiche de la Concepcion, *Liebmann*, no. 543 (by clerical error cited as no. 614 by Klatt, l. c.).

++ ++ Heads somewhat smaller, in fruit 7 to 9 mm. in diameter.

= Tips of the pales recurved.

80. V. SEEMANNII, Sch. Bip. in Seem. Bot. Herald, 306; Hemsl. l. c. 190. — N. W. Mexico, Sierra Madre, *Seemann*, no. 2027 (with well developed pappus); S. W. Chihuahua, *Palmer*, no. 324 (with pappus reduced).

= = Tips of the pales straight.

a. Heads 14 to 25 in a rather small corymb often surpassed by the leaves: cortex of the branches gray, soon glabrate: pedicels tomentose with spreading hairs.

81. V. ABSCONDITA, Klatt, Leopoldina, xx. 93. — Mexico, without locality, *Ehrenberg*, no. 837. Although characterized as being an herb and as having 5-piloso-costate achenes, this species proves (from a detailed drawing by Klatt) to be the plant formerly described by us as *V. Smithii*, Proc. Am. Acad. xxxii. 46, and its range may be more definitely given as follows: Jaycatlan, Oaxaca, altitude 1,300 m., *L. C. Smith*, no. 132; limestone ledges, near Tehuacan, Puebla, *Pringle*, no. 7497.

b. Branches not lanate: heads very numerous in broad corymbs; pedicels silky-canescent with subappressed hairs.

82. V. PERYMENIOIDES, Sch. Bip. in Klatt, l. c. xxiii. 143. — S. Mexico, Yavesia, *Liebmann*, no. 330; Oaxaca, *C. & E. Seler*, no. 33, *Pringle*, no. 4804; *L. C. Smith*, nos. 216, 295, 898 (smoothish form); *E. W. Nelson*, no. 1507.

c. Heads numerous: branches lanate.

1. Tips of the involucral scales squarrose: rays 7 to 8 mm. long: leaves remotely incurved-dentate, 3 to 5 cm. broad.

83. V. OERSTEDIANA, Benth. in Oersted, Vidensk. Meddel. 1852, p. 96; Klatt, l. c. xxiii. 144. — Costa Rica, on the side of the Volcano Irasu, altitude 2,000 to 2,500 m., *Oersted*, *Pittier*, no. 11583.

2. Tips of the involucral scales appressed: rays 1.1 cm. long: leaves essentially entire, 6 to 10 cm. broad.

84. V. **lanata.** Stem stout, pithy, terete, woolly: leaves elliptic-lanceolate, obsoletely denticulate, pubescent upon both surfaces, 1.5 to 2.5 dm. long, 6 to 10 cm. broad, rather abruptly narrowed to a caudate acumination at the apex, gradually narrowed below to a wingless woolly petiole 4 cm. in length: branches of the compound flat-topped many-headed corymbs sordid-lanate or -tomentose; involucre turbinate, about 4-seriate, sordid-tomentulose; scales oblong, obtusish: rays about 10, elliptic-oblong, 6 mm. long, white (?); awns of the pappus long and slender. — *V. Oerstediana*, Donnell Smith, Enum. Pl. Guat. pt. 1, 23, not Benth. — Guatemala, Coban, Depart. Alta Verapaz, *H. von Tuerckheim*, February, 1888, no. 1344 of Mr. J. Donnell Smith's sets.

§ 10. PSEUDOMONTANOA. Heads small: rays yellow: leaves sinuately 3–5-lobed: pales broad.

* Leaves alternate.

85. V. **fastigiata.** Tomentulose, younger parts more or less white-woolly: stems with rather broad herbaceous wings: leaves alternate, palmately 3-lobed, slightly scabrous above, loosely canescent-tomentose beneath, 3-nerved from above the base, 8 to 20 cm. long, 5 to 14 cm. broad, decurrent into winged petioles; nerves prominent beneath: heads numerous, in anthesis 5 mm. in diameter, in fruit 1 to 1.2 cm. in diameter, subglobose, in compound flat-topped fastigiate corymbs; scales of the involucre about 3-seriate, unequal, narrowly ovate, acute, appressed-pubescent and ciliate; pales stramineous, acute, with an erect tip: rays small, pale yellow: achenes broadly winged, pale in color, broadly obovate, the body 3 mm. long; pappus of 2 unequal awns. — Mexico, without locality, *Dr. J. Gregg*, 1848–1849, no. 575.

* * Leaves opposite.

+- Stems broadly winged: outer involucral bracts minute, ovate, acute, somewhat decurrent upon the puberulent pedicels; these subumbellate, 1 to 3 cm. long: Mexican.

86. V. PINNATIFIDA, Cav. Ic. i. 67, t. 100; DC. Prodr. v. 615; Hemsl. l. c. ii. 190, excl. synon. and pl. Oersted. — Cuernavaca, More-

los, *Bourgeau*, no. 1210; near Guadalajara, Jalisco, *Palmer*, no. 698, *Pringle*, no. 1797; Sinaloa, *Lamb*, no. 463, immature.

+ + Stems narrowly winged: outer bracts of the involucre two thirds as long as the inner, oblong, obtuse; pedicels tomentose, 2 to 8 mm. long: Mexican.

87. **V. montanoifolia.** Stems terete, narrowly 4-winged; internodes long: leaves opposite, sinuately and pinnately 3(–5)-lobed, 8 to 16 cm. long, 8 to 13 cm. broad, scabrous above, green and densely pubescent beneath with short stiff spreading hairs; lobes ovate, denticulate not incised: corymbs compound, the primary branches long, but the ultimate tomentose pedicels considerably shorter than in the preceding species: involucral scales 2-seriate, green, 4 to 6 mm. long: rays 8 to 10, bright yellow, 6 mm. long: body of the disk-achene oblanceolate, 4 mm. long, glabrous; wings about equal, rather broad, rounded at the summit; awns 2, long, subequal. — Ravines, Patzcuaro, Michoacan, 11 November, 1890, *C. G. Pringle*, no. 3475.

+ + + Stems with rather narrow wings: pedicels 4 to rarely 16 mm. long, covered with a sordid pubescence: S. American.

83. **V. caracasana.** Shrub 2 to 3 m. high: branches sparingly scabrous-pubescent; wings 4, herbaceous, 1 to 2 mm. in breadth, straight (not crisped as in *V. pinnatifida*): leaves opposite, sinuately 3-lobed, very scabrous and white-punctate above, somewhat paler but green and sordid-pubescent beneath, rather thin, 8 to 16 cm. long, 6 to 11 cm. broad: lobes acute or acuminate, mucronulate-serrulate to dentate, neither lobed nor incised: corymbs ample, at first fastigiate, at length loose: pedicels slender, more or less flexuous, sordid-pubescent; involucre in anthesis cylindrical, 5 mm. in breadth; scales 3–4-seriate, narrowly oblong, acutish, pubescent: rays 6 to 8, little exserted: fruiting heads 1.5 cm. in diameter: achenes broadly obcordate; the body oblong, cuneate at the base, 4 mm. long, somewhat tuberculate; wings broad; awns 2, nearly as long as the achene. — Caracas, *Birschel*, December, 1854; also near Tovar, Venezuela, 1854–1855, at 1,200 m. altitude, *A. Fendler*, no. 693.

+ + + + Stems wingless: Mexican.

89. V. TRILOBATA, Rob. & Greenm. Proc. Am. Acad. xxxii. 46. — Rocky gulches, Monte Alban, Oaxaca, *Pringle*, no. 4875.

§ 11. OCHRACTINIA. Heads small: rays white or nearly so: leaves alternate.

* Herbs of the United States, Mexico, and Fernando do Noronha.

+ Wings of the stem 4 to 5, narrow, seldom attaining the inflorescence: pappus well developed.

90. V. VIRGINICA, L. Spec. ii. 901; DC. Prodr. v. 616. *V. polycephala*, DC. l. c. — Highly variable as to foliage, but without significant or constant technical differences.

a (typical form). Leaves undulate-dentate to entire, not lobed, soft-pubescent beneath: rays about 6 mm. long. — Illinois to Georgia and Texas, common. Ervendberg's no. 58 from Huasteca, S. Mexico, is placed here with doubt.

Var. *β* LACINIATA, Gray. Leaves sinuately lobed: rays as in the typical form. — Syn. Fl. i. pt. 2, 287. *V. laciniata*, Nutt. Gen. ii. 170. *V. sinuata*, Ell. Sk. ii. 411; DC. l. c. 615. — S. Carolina, *Dr. Mellichamp*, to Florida, near the coast.

Var. *γ* **insularis.** Leaves lobed or undivided: rays short, 3 to 4 mm. long, otherwise closely like the typical form. — Fernando do Noronha, *Ridley, Lea, & Romage*, 1887. Type in herb. Gray.

+ + Wings of the stem commonly 6, usually penetrating the inflorescence: leaves mostly sinuate-dentate or deeply crenate: pubescence very short: pappus well developed, half to two thirds as long as the achene: S. W. United States and adj. Mexico.

91. V. MICROPTERA, DC. l. c. 616. — Between Laredo and Bejar, *Berlandier*, nos. 182, 1442; on the Rio Grande near Blancos, *Schott;* Guadelupe, *Palmer*, no. 732 (coll. of 1880); Nuevo Leon, *Berlandier*, June, 1844; Matamoras, *Gregg*.

Var. **mollissima.** Leaves velvety with dense somewhat tawny tomentum beneath. — Valley near Monterey, Nuevo Leon, 7 July, 1888, *C. G. Pringle*, no. 1916, also in Nuevo Leon, *Berlandier*, June, 1843, and on the Rio Coleto, Texas, September, 1850, *G. Thurber*, no. 8.

+ + + Wings of the stem 5 or 6: pappus abortive, scarcely exceeding the narrow wing: outer involucral scales spatulate with an herbaceous tip.

92. V. **rumicifolia.** Stems thick, herbaceous, pithy, finely pubescent, broadly 5(–6?)-winged: leaves alternate, elliptic-lanceolate, large, 1.5 to 2 dm. long, 4 to 8 cm. broad, sharply and doubly sinuate-dentate, acute, narrowed below to a sessile and decurrent base, thin, green and sparsely pubescent on both surfaces; the upper leaves subentire, oblong, elongated, obtuse, crisped on the margins: branches of the corymbose panicle winged; pedicels sordid-villous; heads larger and more numerously flowered than in *V. virginica;* involucral scales canescent-villous,

the outer somewhat spatulate with herbaceous often recurved tips: achenes obovate, glabrous, black and shining, 5 mm. in length, narrowly winged; awns of the pappus very short (0.2 to 0.5 mm. in length). — *V. virginica*, var. *Palmeri*, Gray, acc. to Wats. Proc. Am. Acad. xviii. 106, & xix. 11 (where first described); Hemsl. l. c. iv. 57. — Soledad, Coahuila, Mexico, *Dr. Edw. Palmer*, no. 733 (coll. of 1880). Type in herb. Gray.

* * Trees, shrubs, and gigantic half-shrubs of South Mexico, Central and South America.

+ Leaves broadly lanceolate, very large (7 to 22 cm. in breadth), undivided.

93. **V. punctata.** Stems pale gray, pithy, terete, smooth: leaves alternate, ovate to ovate-lanceolate; the blade 2 to 3 dm. long, 7 to 22 cm. broad, serrate-dentate, slightly scabrous and white-punctate above, green, scarcely paler, veiny and sparsely pubescent beneath, acute, narrowed or abruptly contracted below into a winged petiole: branches of the compound many-headed corymb winged; pedicels filiform, 8 to 14 mm. long; involucre campanulate, 5 to 6 mm. in diameter; scales 3-seriate, ovate, acuminate, ciliolate, otherwise glabrous, the outer much shorter: rays about 8, white, short-oblong: achenes of the disk-flowers (immature) narrowly winged; pappus-awns long and slender. — *V. leprosa*, Coulter in Donnell Smith, Enum. Pl. Guat. pt. 4, 88, not Klatt. — Guatemala, Casillas, and Las Viñas, Depart. Sta. Rosa, *Heyde & Lux*, nos. 4241 and 6176 of Mr. J. Donnell Smith's sets.

+ + Leaves lance-oblong, undivided, 2 to 4 cm. broad, glabrate and very smooth above.

94. V. ACUMINATA, DC. l. c. 614. Shrub or small tree, 2 to 5 m. high, exuding a viscid milky juice: leaves varying from entire to serrate. — *V. Moritziana*, Sch. Bip. acc. to Klatt, Leopoldina, xx. 93. *V. salicifolia*, Klatt, l. c. not HBK. — Caracas, *Vargas*, *Moritz*, no. 832; Tovar, Venezuela, *Fendler*, no. 2352; U. S. Colombia, *Moritz*, no. 833.

+ + + Leaves sinuate-lobed or -pinnatifid occasionally subentire in *V. verbascifolia*.

++ Stems wingless above, soon glabrate and very smooth: leaves deeply pinnatifid, lobes 5 to 11, relatively narrow.

95. V. GIGANTEA, Jacq. Branches wingless. — Ic. Pl. Rar. i. t. 175 & Coll. i. 53; DC. l. c. 615. *V. myriocephala*, Sch. Bip. in Klatt, l. c. xxiii. 144. — Chiapas, near Yajalon, *E. W. Nelson*, no. 3423; St. Augustin, S. Mexico, *Liebmann*, no. 271; Guatemala, Palin and St. Luis, *J. Donnell Smith*, nos. 2861, 2378; Panama, *Seemann*; Jamaica, *Wolf*; Martinique, *Hahn*; Magdalena, U. S. Colombia, *André*, no. 222.

++ ++ Stems winged even to the inflorescence.

= Leaves deeply 9–13-lobed; lobes oblong, acuminate, not very unequal, serrulate.

96. V. PINNATA, Clark acc. to DC. l. c. — Country unknown. Ghiesbreght's no. 782 from Chiapas, Mexico, corresponds well with the description as to foliage, winged stem, etc., but has the stem glabrate as in *V. gigantea*, of which it is probably only a winged form.

= = Leaves deeply 8–9-lobed; lobes oblong, acuminate, not very unequal, serrulate.

97. V. DIVERSIFOLIA, DC. l. c.; Baker in Mart. Fl. Bras. vi. pt. 3, 213, t. 65. ? Britton, Bull. Torr. Club, xix. 150. — Bahia, Brazil, *Blanchet* & *Salzmann*; and probably Coripati, Yungas, Bolivia, *Bang*, no. 2135 (stem winged?). A portion of the type material in herb. Gray. Leaves said to vary to an unlobed form.

= = = Leaves irregularly and seldom deeply lobed, rarely undivided; lobes broad, often obtuse; veins at length very prominent beneath.

98. V. TURBACENSIS, HBK. l. c. iv. 203; DC. l. c.; Klatt, Leopoldina, xx. 93. *V. verbascifolia*, Walp. Bot. Zeit. ix. 63 (wrongly referred to the opposite leaved *V. pinnatifida* by Klatt, l. c.). *V. nicaraguensis* & *V. microcephala*, Benth. in Oersted, Vidensk. Meddel. 1852, p. 97–98; Klatt, Bull. Soc. Bot. Belg. xxxi. 206. *V. pinnatifida*, Hemsl. l. c. 190, in part. — S. Mexico, Oaxaca, *Pringle*, no. 4966, *L. C. Smith*, no. 288, *E. W. Nelson*, no. 1852; Lobani, *Liebmann*, no. 333; Orizaba, *Bourgeau*, no. 3208, *Schaffner*; Costa Rica, *Tonduz*, no. 7247; Guatemala, *von Tuerckheim*, no. 1351 of Mr. J. Donnell Smith's sets; Turbaco, U. S. Colombia, *Humboldt* & *Bonpland*; Tovar, Venezuela, *Fendler*, no. 698; Caracas, *Moritz*, no. 60 (leaves undivided). This species was originally described as having yellow flowers, but this is probably an error. The otherwise excellent description of Kunth and a detailed drawing by Klatt are well matched by the white-flowered plants placed here.

++ ++ ++ Stems wingless, permanently pubescent or tomentose.

99. V. SUBLOBATA, Benth. Pl. Hartw. 76; Hemsl. l. c. 190; Klatt, Leopoldina, xxiii. 144. *V. gigantea*, Coulter in Donnell Smith, Enum. Pl. Guat. pt. 4, 88, not Jacq. — Chiapas, *E. W. Nelson*, no. 3468; Guatemala, *Hartweg*, no. 536, *Salvin* (acc. to Hemsl.), *Heyde* & *Lux*, no. 4238 of Mr. J. Donnell Smith's sets; "Costa Rica & Guatemala," *Warscewicz*, no. 127. *V. tomentosa*, DC. l. c. 614, is a doubtful synonym.

§ 12. Lipactinia. Rays none: heads small.

* Leaves (at least in great part) opposite.

+ Erect shrub: leaves serrate, pubescent: Mexican.

100. V. pauciflora, Hemsl. Biol. Cent.-Am. Bot. ii. 189 (1881). *V. cymosa*, Gray, Proc. Am. Acad. xxi. 390 (1886). — Cerro de Pinal, *Seemann*, no. 1468; S. W. Chihuahua, *Palmer*, no. 135.

+ + Perennial herb: leaves serrate, scabrous: S. American.

101*. V. Grisebachii, Baker, l. c. 214. *V. helianthoides*, Griseb. Symb. Fl. Argent. 194, not Michx. — Argentine Republic, Entre Rios, to Concepcion del Uruguay (acc. to Baker, l. c.).

* * Leaves alternate, bipinnatifid: Brazilian.

102*. V. bipinnatifida, Baker, l. c. 213. — Minas Geraës, Brazil, *Martius*.

* * * Leaves alternate, undivided, auriculate at the base: Mexican.

103. V. auriculata, DC. Prodr. v. 617; Klatt, Leopoldina, xxiii. 144. — Tehuantepec, *Andrieux*, no. 302; Villa Alta, *Liebmann*, no. 211.

* * * * Leaves alternate, undivided, exauriculate.

+ Leaves very large, 1.5 to 3 dm. long, 4 to 8 cm. broad.

++ Brazilian.

= Achenes broadly winged.

104*. V. floribunda, Gardner in Hook. Lond. Jour. Bot. vii. 407; Baker, l. c. 212. — Minas Geraës, *Gardner*, no. 4927.

= = Achenes narrowly winged.

105*. V. nicotianæfolia, Baker, l. c. — Brazil without locality, *Pohl*, no. 621.

++ ++ Andean.

106. V. arborea, HBK. l. c. 202; DC. l. c. 617. *V. Cumingii*, Sch. Bip. Linnæa, xxxiv. 528. — Mountains about Quito, *Humboldt & Bonpland*; near Sorata, Bolivia, *Mandon*, no. 56.

+ + Leaves smaller.

++ Leaves sparingly pubescent beneath.

= Leaves "sessile": heads numerous.

107*. V. guianensis, Baker, l. c. 211. — British Guiana, *Schomburgk*, nos. 194, 654. — Not seen by the writers.

= = Leaves narrowed below to distinct petioles: corymbs few-headed.

108. V. SCHOMBURGKII, Sch. Bip. in Schomb. Faun. Fl. Brit. Guiana, 1078 (name only); Klatt, l. c. xx. 94. — British Guiana, *Schomburgk*, no. 993. A form of the preceding?

++ ++ Leaves densely pubescent beneath.

109. V. CLAUSSENI, Sch. Bip. in Baker, l. c. 212. — Central Brazil, *Claussen, Riedel, Warming, Langsdorf.*

DOUBTFUL SPECIES.

V.? ÆSTUANS, Lam. Dict. iii. 262, DC. Prodr. v. 618 (*Inula æstuans*, L. Spec. ed. 2, ii. 1236), known from Plum. ed. Burm. t. 41, f. 2, is wholly doubtful and probably not of this genus. It has very numerous long narrow linear rays and a multiseriate involucre.

V. ARGENTEA, Bertol. Fl. Guat. 435, if (as described) with neutral ray-flowers and triangular upwardly villous achenes, is probably an *Encelia.*

V. ARGENTEA, Gaud. in Freyc. Voy. Bot. 463, is a very imperfectly characterized plant of the Marian Islands.

V. CONYZOIDES, Trew, Pl. Rar. 8, t. 6 (1763), without locality, does not appear to have been recognized by any subsequent author. We have not had access to the work in which it is figured.

V. DECURRENS, Vell. Fl. Flum. viii. t. 114, represented with racemose heads and a pappus of several capillary bristles, is surely not of this genus.

V. HUMBOLDTII, Spreng. Syst. iii. 577. *V. helianthoides*, HBK. Nov. Gen. & Spec. iv. 204, not Michx. We have seen no material of this species and are unable to place it satisfactorily. It is supposed to come from Ecuador, and is probably related to *V. elegans*, but has leaves "glabrous above." The Mexican plants referred to this species by Klatt are doubtless distinct.

V.? ILICIFOLIA, Poir. Dict. viii. 459, of San Domingo, with opposite short-petiolate coriaceous dentate leaves, is still doubtful.

V. INVOLUCRATA, Rich. Tent. Fl. Abyss. i. 409, is of Abyssinia and of doubtful generic affinities.

V. MAMEANA, André, Rev. Hort. xiv. 16, f. 5 (1885), is a horticultural species described from the stem and foliage alone. There is no satisfactory evidence that it is of this genus.

V. MEGAPOTAMICA, Spreng. Syst. iii. 578; DC. Prodr. v. 618, of the Prov. Rio Grande, Brazil, but unmentioned in the Flora Brasiliensis, is not recognized.

V. POPULIFOLIA, Hill, Hort. Kew. 31, poorly known and probably, like the other Old World species, not really of this genus.

V. PROSTRATA, Hook. & Arn. Bot. Beech. 195, is a prostrate and creeping Chinese plant with somewhat triangular achenes.

V. SCANDENS, Roxb. Hort. Beng. 62, & Fl. Ind. iii. 441, is an E. Indian plant unrecognized by recent writers.

V. SCAPOSA, Jones, Zoe, ii. 248, with scapose chiefly 1-headed peduncles and large radical leaves arising from a tuberous root, is a very doubtful member of the genus, not seen by the writers.

V. TRIPLINERVIA, Vis. Nuov. Sag. Accad. Padova, v. 264, Walp. Rep. ii. 621, said to be Mexican, is unrecognizable from its insufficient characterization.

V. TRIRADIATA, Vell. Fl. Flum. viii. t. 115, is altogether doubtful.

TRANSFERRED SPECIES.

V. ALTERNIFOLIA, Britton in Kearney, Bull. Torr. Club, xx. 485, is *Actinomeris squarrosa*, Nutt.

V. ANCISTROPHORA, Gray, Proc. Am. Acad. xix. 14 (1883), being *Ancistrophora Wrightii*, Gray, Mem. Am. Acad. ser. 2, vi. 457 (1859), is *V. Wrightii*, Griseb. Cat. Pl. Cub. 155 (1866), which should not be displaced by *V. Wrightii*, Gray, Proc. Am. Acad. xix. 12 (1883).

V. BRIDGESII, Rusby, Mem. Torr. Club, iv. 212, is *V. boliviana*, Klatt.

V. CYMOSA, Gray, Proc. Am. Acad. xxi. 390, is *V. pauciflora*, Hemsl.

V. HASTATA, Kellogg ex Curran, Bull. Calif. Acad. i. 140 (1885), is *V. venosa*, Greene, Bull. Torr. Club, ix. 110 (1882).

V. HOOKERI, Klatt, Leopoldina, xx. 92, being *V. helianthoides*, H. & A. in Hook. Jour. Bot. iii. 316, not DC., is *V. Arnottii*, Baker in Mart. Fl. Bras. vi. pt. 3, 215.

V. LINIFOLIA, L. Syst. Nat. ed. 10, ii. 1226, founded on t. 149, f. 3 of Sloane's Hist. Jam., is *Pectis linifolia*, L., which rests on the same plate.

V. OAXACANA, Klatt, l. c. xxiii. 144, not DC., is *V. olivacea*, Klatt.

V. OVATA, Gray, Proc. Am. Acad. xix. 13, is *V. pterocaula* [Moc. & Sess.] DC.

V. PANICULATA, Heller, Cat. N. Am. Pl. 8, not Poir., is *Actinomeris alba*, Torr. & Gray.

V. PERSICIFOLIA, Klatt, Leopoldina, xx. 93, not DC., is *V. virgata*, Cav.

V. PINNATIFIDA, Gray in Wats. Proc. Am. Acad. xxii. 428 (Palmer's no. 698 from Jalisco), certainly not of Cav., is probably sterile *Montanoa grandiflora*, Sch. Bip.

V. PODOCEPHALA, Gray, Pl. Wright. ii. 92, is *Zexmenia podocephala*, Gray, Syn. Fl. i. pt. 2, 286.

V. SARTORII, Sch. Bip. in Klatt, l. c. xxiii. 143, is *V. olivacea*, Klatt.

V. SCANDENS, Klatt, Leopoldina, xxv. 106, is acc. to Klatt, Ann. Natur. Hofmus. Wien, ix. 362, *Salmea Eupatoria*, L.

V. TOMENTOSA, DC. Prodr. v. 614, imperfectly described and without exact locality, may be doubtfully referred to *V. sublobata*, Benth.

V. TRIDENTATA, Spreng. l. c. 577, is *Aspilia buphthalmiflora*, Griseb.

V. TUBEROSA, Klatt, Ann. Natur. Hofmus. Wien, ix. 361, is *Zexmenia aurea*, Benth. & Hook. f. Gen. ii. 373 (*Wedelia? aurea*, D. Don, Bot. Mag. t. 3384; *Verbesina aurea*, DC. Prodr. v. 613).

III. — SOME NEW SPECIES, EXTENDED RANGES, AND NEWLY NOTED IDENTITIES AMONG THE MEXICAN PHANEROGAMS.

By J. M. GREENMAN.

Eleocharis aciculariformis. Perennial: rhizomes dark brown, creeping, rather stout, freely branched: culms 5 to 8 cm. high, tufted at the nodes of the rhizome, vaginate at the base: sheaths reddish-brown below, hyaline above: spikes elliptic-ovate, 4 to 6 mm. long, about 12-flowered; scales ovate, obtuse, somewhat compressed, green on the back with reddish-brown sides and scarious margins: setæ 3, a little over 1 mm. in length: achenes oblong-obovate, about 1 mm. long, rather abruptly narrowed at the summit, longitudinally ribbed, and transversely striated: tubercle about one third as broad as the achene. — Collected by C. G. Pringle in the Valley of Mexico, Federal District, 7 May, 1898, no. 6818.

This species seems most nearly related to *E. acicularis*, R. Br., but differs in the stouter habit, the more conspicuously sheathed culms, and the more persistent and longer setæ.

Smilax Pringlei. Stems terete, unarmed, somewhat tawny-pubescent, later becoming glabrous or nearly so: leaves alternate, ovate or ovate-oblong, 7 to 12 cm. long, 4 to 6.5 cm. broad, cordate or occasionally subtruncate, short-acuminate, acute, entire, 5–7-nerved with rather prominently reticulated veins, glabrous above or slightly pubescent on the nerves, more or less pubescent beneath, later becoming glabrous except on the rather densely hirsute-pubescent nerves; petioles 1.5 to 2 cm. long, pubescent, ceriferous near the base: peduncle 2 to 4.5 cm. long, pubescent; pedicels 6 to 12 mm. long, these as well as the slender flower-buds grayish-puberulent: perianth-divisions of the staminate flowers linear-oblong, 6 to 8 mm. long, 1 to 1.5 mm. broad, obtuse, 1-nerved, in anthesis recurved: pistillate flowers not seen: mature fruit smooth, globose, about 1 cm. long; seeds ovate, 5 mm. long, 8 mm. broad, reddish-brown. — Collected by C. G. Pringle in a barranca near Cuernavaca, State of Morelos, 20 November, 1895, no. 7060, and in the same locality at an altitude of 1,800 m., 18 June, 1896, no. 7259, also in mountain cañon above Cuernavaca, altitude 2,000 m., 15 May, 1898, no. 6843.

A species climbing to 6 m. and most nearly related apparently to *S. erythrocarpa*, Kunth, from which it is distinguished by the pubescent character and by the shorter peduncles.

Agave (Littæa) intrepida. Acaulescent: leaves numerous in a rosette, lance-attenuate, about 4.5 dm. long, 1.5 to 2.5 cm. broad, gradually narrowed to a rather slender reddish-brown end spine, somewhat dilated at the base to a breadth of 2.5 to 4 cm., smooth and in the dried state more or less striate upon either surface, margins cartilaginous, minutely, closely, and evenly serrulate from base to apex: scape 1 to 1.25 m. high, clavate: bracts of the peduncle scattered; floral bracts lance-attenuate, slightly exceeding the flowers, scarious: flowers in pairs, 3.5 to 4 cm. long: perianth-tube 1.2 to 1.4 cm. in length; lobes oblong, somewhat shorter than the tube, slightly thickened at their pubescent apices: stamens inserted at about the middle of the perianth-tube, overtopping the stigma and more than twice exceeding the perianth: capsule 1.7 cm. long, nearly 1 cm. in diameter. — Collected by C. G. Pringle on mossy cliffs, Parque Station, State of Morelos, altitude 2,100 m., 2 June, 1898, no. 6868.

This species is apparently related to *A. dasylirioides*, Jacobi & Bouché, but differs materially in size and habit. In Mr. Pringle's plant the

scape is erect, not pendulous, and the bracts of the peduncle are scattered, not secund and falcate, which is perhaps the most striking character of *A. dasylirioides.* The specific name is suggested by the seemingly perilous habitat of the plant in its native haunts. As stated by Mr. Pringle, *A. intrepida* grows "on the faces and tops of the strange castellated knobs of bare conglomerate, which form a range fifteen to twenty miles to the east of Cuernavaca."

Sisymbrium Coulteri, Hemsl. Diag. Pl. Nov. pars alt. 18, & Biol. Cent.-Am. Bot. i. 35. Specimens of this species were collected by Mr. C. G. Pringle on limestone hills near Pachuca, State of Hidalgo, altitude 2,500 m., 17 August, 1898, no. 6963. In the original characterization the flowers are described as *white*. This character, however, must pertain to the corolla only, as the sepals in the type specimen, namely Parry and Palmer's no. 14 (coll. of 1878), and especially in Mr. Pringle's specimens above cited, are distinctly roseate.

Phaseolus microcarpus, Mart. Ausw. Merkw. Pfl. 18, t. 12 (1850? acc. to Jackson, Lit. Bot. 429). This species, although well characterized and excellently illustrated in the above cited work, seems to have been overlooked and omitted from the more generally used lists of Mexican plants, including Hemsley's Biol. Cent.-Am. Bot. *P. monospermus*, Rob. & Greenm. Proc. Am. Acad. xxix (1894), 385, is now regarded as a synonym of *P. microcarpus*, Mart., and to the latter species may be referred Pringle's no. 5446, collected in a barranca near Tequila, State of Jalisco, and also specimens collected by the late Rev. Lucius C. Smith at Monte Alban, State of Oaxaca, altitude 1,900 m., 11 October, 1895, no. 931.

Croton Ehrenbergii, Schl. Linnæa, xix. 248; DC. Prodr. xv. pt. 2, 636. Specimens collected by Mr. C. G. Pringle at Cerro Ventoso above Pachuca, State of Hidalgo, altitude 2,600 m., 18 August, 1898, no. 6967, are referred confidently to the above species, notwithstanding the slightly larger leaves.

Euphorbia dictyosperma, Fisch. & Mey. Ind. Sem. Hort. Petrop. ii. 37; DC. Prodr. xv. pt. 2, 135. Excellent specimens of this very characteristic species were collected by Mr. C. G. Pringle on wet meadows of the Sierra de Pachuca, State of Hidalgo, altitude 2,900 m., 13 August, 1898, no. 6960. The species seems not to have been hitherto recorded from Mexico.

Styrax Ramirezii. Tree, 9 to 12 m. high: branchlets finely ferrugineous-stellate, furrowed: leaves alternate, petiolate, oblong-lanceolate, 1 to 1.5 dm. long, 3.5 to 5 cm. broad, acuminate, acute or obtusish, cune-

ate at the base, entire, glabrous and smooth upon either surface, or slightly roughened on the prominent midrib and nerves beneath, rather strongly reticulately veined, the lower surface somewhat glaucous: inflorescence racemose; racemes axillary, including the peduncle 6 cm. or less in length; rhachis, pedicels, and the minute bracts closely ferrugineous-stellate: flowers subsecund: calyx cupulate, 5 to 6 mm. high, about equalling the pedicels, shallowly sinuate, 5-dentate, argenteous-lepidote: corolla about 1.5 cm. long; externally and along the margins of the upper surfaces of the lobes argenteous-pubescent or somewhat scaly: filaments and ovary above stellate-pubescent: fruit not seen. — Collected by C. G. Pringle in mountain cañons above Cuernavaca, State of Morelos, altitude 2,000 m., 15 May, 1898, no. 6848.

The species is named in honor of Sr. Dr. José Ramirez, Director of El Instituto Médico Nacional, City of Mexico.

Menodora heliantheмoides, Humb. & Bonpl., var. **parviflora.** Stems several, procumbent, more or less branched, 5 to 20 cm. long: foliage and inflorescence of the species: calyx 6 to 7 mm. long, usually 11-lobed: corolla about 1 cm. long, equally 5-lobed; lobes oblong-elliptic, 6 to 7 mm. long, 3 to 4 mm. broad: mature capsule about 6 mm. high, nearly 1 cm. broad. — Collected by C. G. Pringle on bare hills above Pachuca, State of Hidalgo, altitude 2,600 m., 30 July, 1898, no. 6918.

A well marked variety, differing from the species chiefly by the smaller flowers and less hirsute-pubescent branches.

Sabbatia arenicola. Annual, glabrous throughout: stems 5 to 10 cm. high, dichotomously much-branched, more or less 4-angled: leaves sessile, ovate-oblong to elliptic-oblong, 0.5 to 1.5 cm. long, about one half as broad, obtuse, entire, thickish, inconspicuously 3–5-nerved: flowers terminating the branches, pedunculate: peduncles 0.5 to 1.5 cm. in length: calyx campanulate, pentagonal, later becoming turbinate and strongly 5-ribbed along the angles; lobes lance-oblong, 5 to 10 mm. long, 2 to 4 mm. broad, obtuse, entire: corolla lilac or rose-purple, about 1 cm. or more in diameter, yellowish in the throat, persistent; lobes obovate-rotund: stamens adnate to the throat of the corolla; filaments one half as long as the corolla-lobes: mature capsule 5 to 6 mm. long; seeds strongly reticulated. — Collected by C. G. Pringle on damp sands of seacoast near Tampico, State of Tamaulipas, 28 April, 1898, no. 6808.

A species most nearly related to *S. campestris*, Nutt., but readily distinguished by the less attenuate calyx-lobes and the much smaller corolla.

Acerates Pringlei. Stems 10 to 20 in clumps, stout, herbaceous, rather densely and finely pubescent: leaves opposite, short-petiolate, ovate or ovate-oblong, 6.5 to 10.5 cm. long, 3 to 6 cm. broad, acute, entire, somewhat truncate or subcordate at the base, rarely slightly narrowed below, sparingly pubescent to essentially glabrous above, paler and pubescent especially upon the prominent veins beneath; petioles 4 to 14 mm. long, canaliculate and often bearing above at the junction of the blade several small gland-like bodies: inflorescence lateral, extending well down on the stem, interpetiolar; peduncles 3 to 8.5 cm. in length, many-flowered, these as well as the pedicels (1.2 to 1.5 cm. long) closely pubescent or subtomentose: bracts linear, setaceous, about 6 mm. long, fugaceous; flowers about 5 mm. high: sepals linear, acute, 4 mm. long, externally pubescent: lobes of the corolla oblong, 5 mm. in length, usually slightly retuse at the apex, glabrous, externally more or less purplish and with the purplish-tinged sepals early reflexed: collar of the gynostegium short but distinct, the short ovate-oblong incurved-auricled hoods of the crown exceeding the gynostegium and entirely devoid of any horn-like process: immature follicles somewhat ovoid or slightly ovate-oblong, short-acuminate, slightly puberulent: seeds reddish-brown, smooth, about 8 mm. broad. — Collected by C. G. Pringle, on the Sierra de Ajusco, State of Morelos, altitude 2,800 m., 21 May, 1898, no. 6853 (in flower), and on the Plan de Salazar, State of Mexico, altitude 3,000 m., 13 August, 1896, no. 7309 (in fruit).

A species superficially resembling *Asclepias neglecta*, Hemsley, but distinctly different in floral structure.

GONOLOBUS (§ CHTHAMALIA) BIFIDUS, Hemsl. Biol. Cent.-Am. Bot. ii. 330. *G.* (§ *Chthamalia*) *Schaffneri*, Gray, in Hemsl. l. c. 334. After a careful examination and comparison of the type specimens representing these two species there can be no doubt as to their absolute identity, and the name of Dr. Gray must give way to that of Hemsley by right of priority of position.

Here also may be referred Pringle's no. 6898, collected on the plains near Pachuca, State of Hidalgo, altitude 2,500 m., 8 July, 1898.

IPOMŒA NYMPHÆIFOLIA, Griseb. Cat. Pl. Cub. 203. It is interesting to note that this characteristic West Indian species was collected by C. & E. Seler in Chiapas, 11 February, 1896, no. 1802. This species seems not to have been hitherto reported from Mexico.

Macromeria Pringlei. Stems herbaceous, erect, about 4 dm. high, branching from a perennial base, subappressed, hirsute-pubescent: leaves sessile or nearly so, lance-oblong, 5 to 11 cm. long, 1 to 3 cm. broad,

acuminate, acute, entire, appressed-tuberculate-hispid above, more or less appressed-hirsute-hispid slightly paler and prominently nerved beneath: inflorescence terminal; pedicels 5 to 6 mm. long: calyx 8 to 10 mm. long, deeply 5-parted, canescent-hirsute; lobes linear, acute: corolla 4 to 4.5 cm. long, covered externally with a spreading hirsute pubescence; lobes ovate-oblong, about 8 mm. long, obtuse: stamens nearly or quite equalling the corolla. — Collected by C. G. Pringle under firs, on the Sierra de Pachuca, State of Hidalgo, altitude 3,000 m., 4 August, 1898, no. 6949.

Solanum jaliscanum. Stems ligneous, unarmed, covered below with a grayish-green cortex, the younger branches, as well as the foliage, pedicels, and calyx, stellate-pubescent: leaves thin, submembranous, usually in pairs, very unequal in size, the larger 8 to 13 cm. long, 2.5 to 4.5 cm. broad, the smaller less than half as large, obtuse, gradually narrowed at the more or less unequal base into a petiole 5 to 20 mm. in length, stellate-pubescent on either surface: inflorescence in sessile extra-axillary umbels: pedicels during anthesis 8 mm. or less in length, later erect, about 1 cm. long: calyx 5 to 7 mm. long, 5-lobed; lobes somewhat irregular, ovate-oblong to oblong-linear, obtuse: corolla rotate, about 1 cm. in diameter; lobes ovate, acute, externally stellate-pubescent, the upper or inner surface glabrous: stamens equal, about 2.5 mm. long: fruit globular, smooth, nearly or quite 1 cm. in diameter. — Collected by C. G. Pringle, barranca of Guadalajara, State of Jalisco, 29 June, 1889, no. 2909, and in the same locality, altitude 1,200 m., 10 June, 1898, no. 6870.

A species having the general habit of *S. capsicastrum*, Link, *S. validum*, Rusby, and *S. lignescens*, Fernald, and perhaps most nearly related to the last, from which, however, it is distinguished by the larger thinner leaves, the somewhat smaller corollas, and erect fruiting pedicels.

SOLANUM JASMINIFOLIUM, Sendt. in Mart. Fl. Bras. x. 13; DC. Prodr. xiii. pt. 1, 81. Specimens collected by Mr. C. G. Pringle in hedges about Cuernavaca, State of Hidalgo, altitude 1,500 m., 25 June, 1898, no. 6901, are referred to the above species, hitherto unreported from Mexico. The leaves on the specimens at hand from Mr. Pringle are for the most part simple and entire. Several specimens, however, of *S. jasminifolium* in the Gray Herbarium have leaves from entire to deeply pinnatisect, thus indicating considerable variability as to foliage. It may be said further that it is difficult to separate from this species the nearly related and also South American *S. boerhaviæfolium*, Sendt. l. c. 48, t. 11.

Cestrum flavescens. Shrub, about 1 m. in height: stems covered with a light grayish bark, the young shoots finely pubescent: leaves ovate to ovate-elliptic, 3 to 5 cm. long, one half to two thirds as broad, obtuse, narrowed at the base into a slightly winged petiole (5 to 10 mm. in length), more or less pubescent on either surface, especially on the veins beneath: inflorescence subracemose at the ends of the branches; peduncles and sometimes the pedicels apparently adnate to the base of the petioles: calyx about 5 mm. long, 5-lobed; tube glabrous or slightly puberulent; lobes triangular-ovate, a little irregular, 1 to 1.5 mm. long, acute, tomentulose at the tips: corolla 2 to 2.5 cm. long, reddish-yellow, tubular, gradually ampliated above, constricted at the throat, glabrous; lobes broadly ovate, about 2 mm. long, obtuse, pubescent along the margins, reflexed: stamens included, glabrous: immature fruit glabrous. — Collected by C. G. Pringle, in lava fields near Cuernavaca, State of Morelos, altitude 1500 m., 11 May, 1898, no. 6832.

In general appearance this species bears a superficial resemblance to the Guatemalan *C. Regelii*, Planch. Fl. Serres, ix. t. 946; but from the latter Mr. Pringle's plant is amply different, in the less acuminate leaves, the shorter and broader calyx-lobes, and finally in the longer and more slender corollas.

PITHECOCTENIUM BUCCINATORIUM, DC. Prodr. ix. 195. *Bignonia buccinatoria*, Mairet in DC. l. c.; Hemsl. Biol. Cent.-Am. Bot. ii. 490; Hooker in Bot. Mag. t. 7516.

In 1878 Parry and Palmer collected in the mountains of San Luis Potosi both flowering and fruiting specimens of this species, and later in 1880 complete specimens were secured by Prof. Dugès in the vicinity of Guanajuato. The characters of the fruit, hitherto unknown, clearly indicate that the affinity of the plant is with the genus *Pithecoctenium* and not with *Bignonia*. The following supplementary description may be given: capsule oblong-elliptic, 1.4 to 1.6 dm. in length, about 6 cm. broad, somewhat narrowed at either end and densely echinate over the entire surface; valves at maturity falling away from the replum: seeds disposed in 4 to 5 rows. To this species may be referred specimens from the following stations: San Luis Potosi, *Parry & Palmer*, no. 695, *Schaffner*, no. 746; vicinity of Guanajuato, *Dugès* (coll. of 1880), without number; Puebla, *Bilimek*, no. 230, and by the same collector at "Cakobaya," no. 229; and in the cultivated state at Orizaba, *Botteri*, no. 915, and *A. Gray* (coll. of 1885), without number.

Ruellia malacosperma. Perennial, conspicuously lineolate throughout: stems 3 to 5 dm. high, erect or ascending from a ligneous base, te-

rete or obtusely 4-angled, glabrous or sparingly villous: leaves opposite, oblong-lanceolate, including the narrow less villous petiole 5 to 13 cm. long, 1 to 3 cm. broad, acuminate, acute or the lower obtuse or even rounded at the apex, narrowed at the base into a petiole, entire or subrepand, densely lineolate on either surface, and with a few scattered villous hairs on the midrib and margins, especially towards the base: inflorescence cymose-paniculate; peduncles 4 to 6 cm. long; pedicels 0.5 to 1.5 cm. long; bracts and bracteoles lance-linear, 1 cm. or less in length: calyx deeply and regularly 5-parted; tube 2 to 4 mm. long; divisions linear-attenuate, 1 to 2 cm. long, these as well as the pedicels densely lineolate and stipitate-glandular, not hirsute: corolla purple, 4 to 5.5 cm. long, tubular-funnelform, externally puberulent; tube slender below, ampliated above; lobes subrotund, 1.5 cm. or more broad: mature capsules 2.5 to 3 cm. long, glabrous, about 15-seeded; seeds slightly oblique, 3 mm. broad, flattened, canescent. — Collected by C. G. Pringle in lowlands near Tampico, State of Tamaulipas, 30 April, 1898, no. 6806; and by Dr. Edward Palmer in the vicinity of Acapulco, October, 1894, to March, 1895, no. 570 (distributed as *Ruellia? ovalifolia*, Hemsl. ex char.?); also by Botteri at Orizaba, in herb. Gray without number.

A species having its affinity apparently with *R. dipteracanthus*, Hemsl., and *R. tuberosa*, L., but differing from the former by inflorescence and longer corolla, also by the character of the calyx, and from the latter by the foliar characters. The seeds of this plant in the dried state are covered with an appressed canescent pubescence, which however, when moistened, is more or less spreading and almost velvety, hence the specific name.

Randia canescens. Shrub or small tree, 3 to 5 m. high: stems terete, covered with a grayish bark; spines 5 to 10 mm. in length: leaves broadly obovate, 1 to 1.5 cm. long, nearly as broad, abruptly narrowed below into a short petiole or subsessile, rounded or obtuse at the apex, canescent-pubescent on either surface: flowers solitary, terminating short axillary branches: calyx-tube about 4 mm. long, appressed-canescent-pubescent; lobes linear, acute, about equalling the tube, grayish-pubescent: corolla salverform; tube nearly 1 cm. long, somewhat folded on itself near the middle, externally pubescent, internally glabrous: lobes somewhat thickened, broadly ovate, about 6 mm. long, nearly as broad, obtuse or rounded at the apex, glabrous above, ciliate: fruit not seen. — Collected by C. G. Pringle in barrancas near Cuernavaca, State of Morelos, altitude 1,500 m., 28 May, 1898, no. 6863.

Randia Nelsonii. Stems sparingly armed, covered with a grayish or reddish-brown bark, rather numerously dotted with lenticels; the young shoots pubescent: leaves thin in texture, obovate or subcuneate, 1.5 to 3 cm. long, two thirds as broad, narrowed at the base into a short petiole, usually rounded, but occasionally slightly retuse, obtuse, or even short acuminate-apiculate at the apex, soft-pubescent on either surface: flowers axillary, solitary, sessile: calyx including the slender spreading lobes not exceeding 5 mm. in length, canescent-pubescent especially on the tube: corolla including the lobes 2.5 to 3 cm. long; tube about 1.5 cm. long, externally puberulent, internally pubescent in the upper half; lobes oblong-ovate, obtuse, nearly glabrous. — Collected by E. W. Nelson on the way from Juchitan to Chivela, State of Oaxaca, altitude 46 to 277 m., 1895, no. 2635.

A species somewhat resembling *R. Pringlei*, Gray, but readily distinguished from it by the texture of the leaves, the infloresence, the longer corolla, and shorter calyx-lobes.

Eupatorium Conzattii. Glabrous throughout: stems herbaceous, ancipitally compressed and subhexagonal, striate, reddish-brown: leaves petiolate, oblong-lanceolate, 5 to 15 cm. long, 2 to 6 cm. broad, acuminate, acute, obtuse or somewhat rounded at the base and slightly decurrent on the (7 to 20 mm. long) petioles, crenate-dentate, distinctly 3-nerved from above the base, conspicuously veined, pellucid-punctate: inflorescence terminating the stems in a compound pyramidal panicle: heads 8 to 9 mm. long, clustered at the tips of the branchlets in threes or fives, sessile or short-pedicellate, 5–6-flowered; involucre cylindrical; scales imbricated, 5–6-seriate, oblong, obtuse or rounded at the tip, distinctly nerved, purplish or stramineous, the outer gradually shorter and darker: flowers about 8 mm. long: achenes 4 mm. long, glabrous; pappus equalling the corollas. — Collected by Prof. C. Conzatti in humid forests on the Cerro del Chiquihuite, Colonia Melchor Ocampo, Cordoba, State of Vera Cruz, altitude 1,300 m., 7 December, 1895, no 17.

This species may be recognized readily by the 3-nerved prominently veined pellucid-punctate leaves associated with the few-flowered cylindrical heads. In general aspect *E. Conzattii* resembles *E. vanillosmoides*, Sch. Bip., but is easily distinguished from it by the venation of the leaves. From *E. tepicanum*, Hemsl., which is said to have ovate-lanceolate pellucid-punctate leaves, our plant differs in having herbaceous instead of woody branches.

Eupatorium leptodictyon, Gray, in Wats. Proc. Am. Acad. xxii. 420. Excellent specimens of this characteristic species were collected by

Dr. Rose in the Sierra Madre, State of Tepic, nos. 1984, 3418. The following supplementary characters may be appended: stems herbaceous from a thick perennial base, 5 to 6 dm. high, simple or sparingly branched: leaves usually alternate, not unfrequently opposite or at least subopposite. *E. leptodictyon* closely resembles *E. strictum*, Gray, but may be distinguished readily from it by the fewer broader and more blunt bracts of the involucre, and by the larger flowers.

Grindelia glandulosa. Apparently biennial: root somewhat obconical: stems subcespitose, erect, simple or sparingly branched, 2 to 3 dm. high, glandular-pubescent with spreading hairs intermixed: basal leaves spatulate, attenuate at the base, including the petiole 6 to 10 cm. long, 1 cm. or less in breadth; stem leaves narrowly oblong or oblong-lanceolate, slightly broadened at the sessile subclasping base, acute, regularly and rather closely serrate, glandular-pubescent upon either surface, 2.5 to 5 cm. long, 6 to 10 mm. wide; the uppermost leaves gradually reduced and more or less acuminate: heads terminating the stems, solitary, excluding the rays 1.5 to 2 cm. in diameter; involucral scales strongly imbricated, purplish, lanceolate, acuminate, terminated by an acutish glandular-viscid tip; margins thin, purplish, suberose, glandular-ciliate, the outer somewhat narrower: ray-flowers 20 to 35; ligules oblong-spatulate, including the tubular portion nearly 2 cm. long: pappus usually bisetose, rarely trisetose or sometimes with a single awn, fugaceous: achenes smooth. — Collected by C. G. Pringle in wet meadows of the Sierra de Pachuca, State of Hidalgo, altitude 3,000 m., 13 August, 1898, no. 6962. Seemingly a very distinct species, readily recognized by the glandular character of the pubescence throughout the entire plant.

Baccharis macrocephala, Sch. Bip. in herb. Gray. Perennial, glabrous throughout: stems somewhat striated, covered with a grayish bark: leaves scattered, sessile, spatulate-lanceolate, 2 to 3 cm. long, 3 to 6 mm. broad, acute, often with a sharply recurved apex, entire and usually hispidulous on the margins or with a few remote horizontally spreading teeth near the apex, glandular-dotted on either surface and more or less viscid, 1–3-nerved, the leaves of the flowering branches much smaller and more or less squarrose-imbricated: inflorescence paniculate-virgate, leafy: heads terminating the branches of the inflorescence, those of the fertile plant nearly or quite 1.5 cm. high, many(90–100)-flowered: involucral scales unequal, 6–7-seriate, imbricated, lance-linear with a dark green midnerve, acute, glabrous, margins scarious and often slightly erose, the inner about 7 mm. long, the outer shorter: pappus white or slightly tawny, nearly or quite 1 cm. in length; achenes glabrous: heads of the staminate

plant about 1 cm. high. — Collected by C. Sartorius in Vera Cruz, altitude 2,700 m., April, 1856; and by C. G. Pringle, Serrania de Ajusco, Federal District, altitude 2,700 m., 23 May, 1898, no. 6859.

A species resembling in habit *B. ramiflora*, var. *squarrulosa*, Gray, but having larger and more numerously flowered heads, and a longer pappus, also related apparently to *B. squarrosa*, HBK., from which, however, it is distinguished by the entire absence of the squarrose character of the involucral scales. Only staminate plants were collected by Sartorius, yet the specimen in herb. Gray in the inflorescence, foliar and involucral characters, agrees so closely with Mr. Pringle's specimens that the writer has no hesitation in referring both to the above hitherto unpublished species.

Desmanthodium lanceolatum. Herbaceous, perennial (?): stems 1 to nearly 2 m. high, freely branching above, striate, glabrous, purplish; internodes much exceeding the leaves: leaves lanceolate to lance-ovate, acuminate, acute, 5 to 10 cm. long, 2 to 4 cm. broad, narrowed below into a subpetiolate base, sharply and somewhat unequally dentate with prominent and more or less divaricately spreading teeth, essentially glabrous upon either surface, paler beneath, margins ciliate-hispid: heads terminating the branches in sessile dense glomerules disposed in a cymose-panicle: bracts broadly ovate, acute, glabrous; margins whitish or subscarious: fertile achenes elliptic-oblong, narrowed at either end, 3 mm. long, black, shining. — Collected by C. G. Pringle, on mountains above Cuernavaca, State of Morelos, altitude 2,100 m., 9 August, 1898, no. 6940.

This species is similar in habit and inflorescence to *D. ovatum*, Benth., but easily distinguished by the lanceolate sharply dentate leaves, and by larger and less obovate achenes.

LEPACHYS COLUMNARIS, Torr. & Gray, var. PULCHERRIMA, Torr. & Gray, Fl. ii. 315; Gray, Syn. Fl. i. pt. 2, 264. *Obeliscaria pulcherrima*, DC. Prodr. v. 559. *Ratibida columnaris*, var. *pulcherrima*, Don in Sweet, Brit. Fl. Gard. n. s. iv. t. 361.

To this well marked variety, characterized by the brown-purple rays more or less bordered with yellow, the following Mexican specimens may be referred. — Coahuila, Carrizilos, 28 May, 1847, *Gregg*, no. 60, *Palmer*, no. 717 (coll. of 1880); Nuevo Leon, 28 September, 1897, *Rose*, no. 3077.

Bidens decumbens. Stems decumbent, 1.5 to 3 m. long, tetragonal, striate, glabrous except at the nodes, purplish: leaves simple and broadly ovate, oblong-ovate to obovate, or pinnately 3-parted (the terminal division often rhombic-ovate, the lateral divisions obovate, unequal at the

base), decurrent into a petiole, acute or short-acuminate, mucronate, crenate-serrate with mucronate teeth, cuneate at the base, thickish, conspicuously veined, glabrous upon either surface or with a few scattered hairs on the midrib beneath; petioles 8 to 20 mm. long, channelled above, usually ciliate: inflorescence cymose or cymose-paniculate, few-headed; peduncles 1 to 3 cm. long: heads about 1 cm. high, radiate; outer scales of the involucre about 14, spatulate, 4 mm. long, obtuse, ciliate, the inner lance-oblong, 6 to 7 mm. long, narrowed near the obtuse puberulent tip: ray-flowers sterile; achenes 3-angular, exaristate; rays oblong-obovate, 2 cm. long, 8 mm. broad, white with yellowish nerves: disk-flowers numerous; mature achenes linear, 6 to 10 mm. long, longitudinally ribbed, glabrous or hispidulous on the angles especially towards the apex, 2–4-aristate. — Collected by C. G. Pringle on sand dunes near Tampico, State of Tamaulipas, 29 April, 1898, no. 6820.

Bahia xylopoda. Perennial: stems decumbent, branching from the base: branches ascending, about 1.5 dm. high, more or less hoary-pubescent: leaves opposite or alternate, triternately compound, segments linear or subterete, obtusish, hirtellous-puberulent: heads radiate, about 1 cm. high, usually long-pedunculate, erect or nodding: involucral bracts subbiseriate, the outer oblong, somewhat truncate, rounded or obtuse at the apex, the inner often more narrowed at either end and acutish, veiny with thinnish margins, grayish-white-pubescent on the outer surface with stipitate glandular hairs intermixed: ray-flowers fertile; ligules including the pubescent tube nearly or quite 1 cm. long; disk-flowers numerous; pappus usually of 8 narrowly oblong-obovate subequal scales, about 2 mm. long, cuneate at the base: corollas of the disk-flowers 4 mm. long, below pubescent on the outside: mature achenes 5 to 6 mm. long, hirtellous-pubescent above, canescent on the angles of the slender base. — Collected by C. G. Pringle, on bare hills above Pachuca, State of Hidalgo, altitude 2,600 m., 30 July, 1898, no. 6931.

This species is nearly related to *B. Pringlei*, Greenm., but is distinguished readily by the longer achenes, narrower scales of the pappus, and also, according to Mr. Pringle, by the entire absence of running roots.

Cacalia ampullacea. Stems 1 to 2 m. high, striate, purplish, puberulent: lower leaves petiolate, oblong-ovate, 2 to 3 dm. long, two thirds as broad, membranous, pubescent above, white-tomentose beneath, about 13-lobed, with rounded sinuses, the main lobes 6 cm. or less long, these again irregularly dentate-lobed; stem leaves sessile, ovate-oblong, 1 dm. or less long, 1 to 1.5 cm. broad, strongly saccate below and surrounding the stem: inflorescence rather densely corymbose: peduncles

and pedicels tomentulose; bracts linear, setaceous; heads about 1 cm. high, 5–6-flowered; scales of the involucre 5 to 6, oblong-oblanceolate, 8 mm. long, 2 to 3 mm. wide, obtuse and slightly pubescent at the apex, otherwise glabrous; margins thin, subscarious: pappus somewhat tawny, about 5 mm. long; corolla glabrous: achenes pubescent. — Collected by C. G. Pringle along streams on the Sierra de Pachuca, State of Hidalgo, altitude 2,700 m., 17 July, 1898, no. 6917.

A species having its affinity with *C. tussilaginoides*, HBK., and *C. amplifolia*, DC. From the former it is distinguished by the outline and general character of the leaves, and from the latter by the white tomentum on the lower surface of the leaves, and the pubescent achenes.

Lactuca brachyrrhyncha. An erect herbaceous annual: stems 1 m. or more high, glabrous or nearly so, purplish: leaves lance-attenuate, 1 to 1.3 dm. long, about 1 cm. broad, acute, entire or remotely denticulate, sessile by a clasping sagittate base, glabrous upon either surface or bearing on the midrib beneath, especially towards the base, scattered rather long hairs, these often continuing with the subdecurrent midrib to the stem, the upper leaves gradually reduced: inflorescence in a terminal panicle; peduncles bracteate; heads 1.2 to 1.5 cm. high, about 20-flowered; involucral bracts imbricated, more or less deeply colored with purple, the outer short, ovate, acutish, the inner lance-linear: flowers blue: pappus white: achenes oblong-elliptic, 4 mm. long, one half as broad, abruptly contracted at the summit into a short beak less than 1 mm. in length. — Collected by C. G. Pringle at Tlalnepantla, Valley of Mexico, Federal District, 6 July, 1898, no. 6883.

A species habitually like *L. integrifolia*, Bigel., from which it is readily distinguished by the short yet distinct beak of the achenes.

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CONTRIBUTIONS FROM THE HARVARD MINERALOGICAL MUSEUM.

VIII. — *PETROGRAPHICAL NOTES ON SOME ROCKS FROM THE FIJI ISLANDS.*

By Arthur S. Eakle.

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By Arthur S. Eakle.

Presented by John E. Wolff, April 12, 1899. Received April 15, 1899.

A collection, consisting of specimens of volcanic rocks from the various islands of the Fiji group, collected by Mr. Alexander Agassiz during the winter of 1897–98, was kindly placed in the hands of the writer for a petrographical study. Each of the islands is, in general, represented by specimens from one locality only, since the purpose was to obtain simply an idea of the nature of the island rock, and not to obtain a complete petrographical knowledge of the islands. In the case of the very small islands, some of which are simply single exposed rocks, the specimens collected can be considered as representative, but with the majority of the islands structural and mineral differences may, and probably do, exist in the rocks from different localities. The description, therefore, of the specimen or specimens from each island, as given in this paper, cannot be offered as the representative petrography of the island.

The Fiji group comprises two large islands, Viti Levu or Great Fiji and Vanua Levu, together with a multitude of much smaller ones lying east, south, and west of Viti Levu. Many of these small islands were visited by Mr. Agassiz, and specimens from about twenty-five of them were collected.

In 1876 Th. Kleinschmidt visited some of these islands and collected specimens of the rocks for the Museum Godeffroy in Hamburg.* These specimens were later studied by Arthur Wichman,† and it is from his published results that we have gained the most of our present knowledge of the petrography of these islands.

* Journ. Museum Godeffroy, 1879, XIV. 264.
† Min. und petrog. Mitth., 1883, V. 1–60.

Viti Levu, besides being the largest and most important island of the group, possesses much more geological interest than the rest of the islands, since it is essentially different in its rock formations. Wichman has shown that granites, syenites, diorites, and gabbros occur on this island, as well as crystalline schists and limestones; and he reaches the conclusion that the island was an old continental mass composed of these older plutonic rocks which stood above the water during the whole of the Paleozoic and Mesozoic ages. During the Tertiary the island was submerged, and received its stratified deposits of limestone, sandstone, and conglomerate, and was also rent by volcanoes. A few specimens from the interior of the island were given to Mr. Agassiz, one of them being a small piece of dioritic granite having the typical hypidiomorphic granular structure, and thus tending to confirm the presence of plutonic rocks on the island.

The large island of Vanua Levu, which lies northeast of Viti Levu, is said to be similar to Viti Levu in structure, but very little is known about it. Kleinschmidt describes a visit to the hot springs on it, but apparently made no petrographical collections. The rest of the islands of the group are volcanic or of coral formation.

The various types of igneous rocks found in the collection might be conveniently included under the following heads: —

Dioritic granite.	Hypersthene andesite.
Augite andesite.	Hornblende andesite.
Augite-biotite andesite.	Basalt.
Augite-olivine andesite.	Olivine basalt.

Andesites and basalts are the characteristic rocks of the region, and they show the usual variations in structure and mineral components. Augite andesite seems to be the predominating rock of the islands, and it varies from types having a small amount of augite with a large amount of feldspar, with biotite as an accessory, to those in which augite is the dominant constituent, showing a gradation into a basalt. Hypersthene andesite was shown by one specimen, so it can be considered as of rare occurrence. Hornblende andesite is more common, yet is also very limited in amount compared to the augite andesite. In fact, the more basic type of the andesitic family predominates, augite, olivine, and labradorite forming the most abundant constituents of the specimens.

In the description which follows each island represented in the collection has its specimen or specimens described in detail.

Viti Levu.

Specimens of eruptives were obtained by gift from three localities on this island.

Kai Vatu Lola.—Specimens of jasper, quartz, and the granite previously mentioned are labelled from this place, which is believed to be in the central part of the island.

The granite megascopically presents a white granular rock, having plates of dark hornblende well disseminated through it. The structure is hypidiomorphic granular, and the composition is essentially of plagioclase feldspar with green hornblende plates and quartz grains. Most of the feldspar sections exhibit fine polysynthetic twinning combined very often with Carlsbad twinning. The extinction angles on sections normal to the brachypinacoid 010 vary from a small angle up to a maximum extinction of 18°. The index of refraction of the sections showing the larger extinction angles is slightly below that of the Canada balsam, indicating albite as the feldspar, while oligoclase is also present, but not so prominent. A few sections of orthoclase more cloudy in appearance than the plagioclases occur, and also two or three sections of microcline showing a beautiful grating structure. The feldspars are in general quite fresh and free from inclusions with the exception of an occasional apatite and zircon crystal. A few of the smaller sections possess good crystal boundaries.

Hornblende is abundant in plates with ends usually frayed out. Much of it is altered to yellowish green chlorite and granular epidote and the formation of some calcite. The fresh hornblende shows strong pleochroism.

Quartz is not very abundant in the rock, and cannot be detected in the hand specimen. A few basal and prismatic anhedrons are seen however in the thin section as an original filling between the feldspars. Magnetite occurs which is evidently titaniferous, as it usually has a border of grayish leucoxene surrounding the grains.

An analysis of this rock would doubtless show a large percentage of soda in its composition because of the large amount of albite present, as well as of oligoclase, and the small amount of potash feldspar. While designated here as a dioritic granite, it might perhaps equally well be considered a quartz diorite. It is the only one of the specimens in the collection which is not effusive in its origin. Wichman describes an amphibole granite very rich in plagioclase from Muanivatu Mountains*

* *Loc. cit.*, p. 8.

in the island, which agrees quite closely with this rock, and may possibly be the same rock.

Mt. Victoria. — A specimen of augite andesite is from this mountain, which rises in the northern part of the island. The rock shows megascopic prisms of augite, magnetite grains, and a few feldspars in a dense greenish black base. Under the microscope the groundmass appears as a web of feldspar and augite microlites with many magnetite grains, cemented by a colorless to yellowish glass, the whole having a hyalopilitic structure.

Plagioclase, augite, and anhedrons of magnetite occur as phenocrysts. The feldspar phenocrysts predominate. The sections are large twinned plates and give an average extinction of 28° normal to 010, showing them to be labradorite. Zonal structure is seen well in some of the brachypinacoidal sections, and the extinction angles of the zones range from +7° on the outer shell to −39° in the centre. Colorless and yellowish glass inclusions are abundant in the feldspar phenocrysts in zonal arrangement. Augite or diopside occurs in pale green, large basal and prismatic sections occasionally containing inclusions of glass and magnetite with a few apatite needles.

The feldspar and augite phenocrysts have been penetrated along the cleavages and fissures by a yellowish brown oxide of iron which also lines some of the cavities with brown banded layers. This oxide has apparently been derived from an iron-rich olivine, whose former presence is indicated by a few irregular sections of fibrous serpentine mixed with brown iron oxide and carbonates.

The base of the rock weathers to a light brown, leaving the augite crystals standing out prominently unaltered.

Na dari Vatu. — An olivine-bearing augite andesite is labelled from this locality, which is said to be in the northern part of the island.

The rock has a dark gray holocrystalline base in which megascopic crystals of black augite are prominently disseminated. The base is largely feldspathic, but includes some small augites, although most of the pyroxenic constituent of the rock is in large phenocrysts.

Plagioclase, augite, and olivine are the chief constituents.

Sections normal to 010 of the feldspars give an average extinction of 22°, indicating an andesine or perhaps the soda-lime end of labradorite, as the kind of plagioclase phenocrysts. Zonal structure is common, and inclusions of the older formed minerals augite, olivine, and apatite, besides much glass, zonally arranged, are seen.

Augite occurs in automorphic sections, containing apatite and olivine inclusions. It is subordinate to the feldspars in amount.

Olivine is present in large and small irregular grains, but is not abundant. A slight serpentinization has taken place along some of the fissures.

Small grains of magnetite occur.

Besides these eruptive rocks just described from Viti Levu, a few specimens of sedimentary formation were collected from along the southern shore of the island. One of them is a coarse conglomerate, which forms a bluff near Suva. It consists of large rounded pebbles and fragments of rock, apparently decomposed andesite, cemented by a very impure calcareous cement. A specimen of a compact white limestone, somewhat siliceous and stained slightly yellowish by iron oxide was collected from a locality twenty-five miles up the Singatoka River.

Specimens were also brought from the two very small islands, Viwa and Mbau, which are close to the eastern coast of Viti Levu. From Viwa is a dark gray compact fossiliferous limestone, and from Mbau a brown decomposed mass termed "soapstone," apparently a sedimentary deposit from an altered eruptive rock.

Augite-biotite Andesite from Na Solo.

The Solo rock on which the lighthouse stands rises just above the water in the centre of the lagoon formed by the North Astrolabe coral reef. Several specimens of this rock were collected, but no differences are seen in any of them.

The rock has a very fine holocrystalline structure with no porphyritic tendency apparent in the hand specimen. It is light ash gray in color, sprinkled with small dark augite crystals.

Microscopically, however, the rock, while not possessing a prominent porphyritic structure, does show many small idiomorphic phenocrysts in a distinctly finer feldspathic base. The feldspars are characterized by isometric forms and zonal structure. Extinctions on the successive zonal layers show a passage from an acid rim to a very basic centre, the maximum extinction in the centres being 35°. The extinction angles of the laths vary from 0° to 20°, the majority being low and indicating oligoclase as the chief feldspar. The Carlsbad and albite twinning are common.

Augite or diopside is well disseminated in the rock as very pale green rounded crystals and fragments. They have all lost their original boundaries, and some have altered to calcite.

Biotite occurs in small brown plates, but is not abundant. It is only

seen in the more acid varieties of the andesites, and therefore appears in but two or three of the rocks from this region. Magnetite is common as fine dust particles and occasionally as anhedrons. A few apatite prisms occur in the feldspars.

HORNBLENDE-ANDESITE FROM KANDAVU.

Kandavu is an irregularly shaped island, stretching northeast to southwest about thirty-two miles long and quite variable in width, lying south of Viti Levu. It is of volcanic origin and has several elevated peaks, that of Mbuke Levu or Mt. Washington, 2,750 feet, being the highest.

Specimens from this mountain are light gray in color, and have phenocrysts of feldspar and hornblende distinctly visible in a glassy base.

Under the microscope the groundmass is seen to be a thick filz of feldspar rods with much magnetite in grains, in a colorless glass, the structure being hyalopilitic. The phenocrysts are mainly plagioclase and hornblende.

The feldspar phenocrysts occur in automorphic plates with a zonal structure. The extinctions of these zonal layers show also a passage from acid rims to basic centres. The small rods of feldspar in the groundmass usually extinguish under 5°, making oligoclase the main feldspar. A few of the large plates contain glass and gas inclusions.

Hornblende is present in yellowish green to deep green pleochroic basal and prismatic sections, having perfect boundaries. Some of the plates are twinned on the orthopinacoid and some show resorption borders. Stout apatites are included. A little calcite has been formed from the alteration of the hornblende.

Biotite is seen in one or two flakes only, showing that it is a rare accessory. A few grains of very pale green, almost colorless pyroxene also occur, probably a diopside ; a few anhedrons of magnetite and some basal and prismatic sections of apatite constitute a part of the accessories.

A specimen collected from the John Wesley bluff, which is on the north shore of the southern half of the island, near Tavukie, is an andesitic tuff, showing remains of hornblende crystals whose contents have been altered to chlorite and calcite with a separation of magnetite, embedded in a dusty amorphous base. Considerable tridymite has formed along the fractures in the rock and in cavities.

Kandavu is the only island of the group besides Viti Levu from which specimens were collected, which have been previously described by Wichman. A description of the hornblende andesite from Mt. Washington is given by him.

Basalt from Mbengha.

Mbengha is a small island lying near the southern coast of Viti Levu.

The structure of the basalt is somewhat intersertal, consisting of stout laths of feldspar with the interspaces filled with a mixture of glass and magnetite grains and some augite microlites.

The feldspar phenocrysts show labradoritic extinctions, and are generally cloudy from numberless brownish glass inclusions and dust particles zonally arranged. The centres of the sections are mostly quite dark with these inclusions, while the rims are pure and colorless.

Augite occurs abundantly as the largest phenocrysts. It is of the common pale green color, non-pleochroic, and occurs in very perfect idiomorphic crystals. They show a well developed cleavage, and often a zonal and also a beautiful hourglass structure. The orthopinacoidal twinning is seen on some of the plates. Large well formed crystals of apatite are present. Yellowish brown stains of iron oxides traverse the groundmass and line the cavities with banded layers.

Specimens were collected from a few of the small islands lying directly west of Viti Levu which appear to belong to the more acidic end of the andesitic group of rocks.

Andesite from Malolo.

Malolo is a small low island lying near the west coast of Viti Levu.

The rock from this island is compact, holocrystalline, and of a lead gray color. It has a feebly polarizing feldspathic base in which frayed out rods of feldspar occur, giving the rock a trachytic appearance. The small laths of feldspar show less than 5° extinction angles. A few small patches of chlorite in bright green plates occur. The specimen is from the surface, and appears as if it had been exposed to the action of the waves, by which its original condition has been changed into a felsitic appearing rock. Magnetite is present in grains.

Andesite from Vatu Mbulo.

Vatu Mbulo is a mere projecting rock above the water, belonging to the Malolo group. In appearance the specimen from this island is very much the same as the preceding. It has the same compact felsitic appearance, with a lead gray color, and seems also to have been altered by the constant exposure to the waves. Under the microscope, however, it shows a few phenocrysts in the base. The groundmass is a mixture of

allotriomorphic feldspar and quartz grains, while both plagioclase and quartz appear as phenocrysts in this microcrystalline base.

An extinction angle normal to the albitic twinning was 20° on the best section. Some of the sections show no polysynthetic twinning, and resemble glassy sanidine with Carlsbad twinning common.

Quartz occurs as an original constituent in large crystals with rounded edges. They contain inclusions of glass and liquid. Some of the sections have a wide resorption rim.

Some of the feldspar has altered to calcite. Magnetite dust is plentiful. There are some areas of yellowish green material which seem to be mixtures of chloritic substance with carbonates, which may have resulted from the alteration of some ferromagnesian mineral, but further than this there is no indication of a dark silicate present.

The rock is perhaps more a dacite than an andesite, but from its present condition little can be learned regarding its former nature.

Hornblende Andesite from Waia.

Waia is a small island three and a half miles long by about three miles wide, lying thirty miles west of Viti Levu. It is one of the most southern of a train of volcanic islands belonging to the Yasawa group, and has several high peaks, one rising 1,870 feet above the sea level.

The specimen from this island is a hornblende andesite having a lead gray color and compact texture. Small glassy feldspars can be detected in the groundmass.

The base lacks glass, and appears microfelsitic with some microlites, and many allotriomorphic grains, of feldspar. Plagioclase phenocrysts occur, having an average extinction on sections normal to 010 of 21°. Polysynthetic and Carlsbad twinning are common. Many of the sections show the zonal structure. Some calcite has been developed from the alteration of the feldspar. Well defined basal and prismatic outlines of hornblende crystals are shown by magnetite, but the original hornblende has completely altered, yielding a mixture of chlorite with calcite.

Pyroxene was also a constituent of the rock, although not so abundant as the hornblende. One crystal, presumably diopside, is seen which has completely altered to calcite.

Magnetite occurs abundantly in fine dust and occasionally in good-sized anhedrons.

This rock is probably the same as the hornblende andesite from Kandavu, but is in a more advanced stage of alteration.

Hypersthene Andesite from Vomo lai lai.

Vomo lai lai is a rock about two hundred feet high on the island of Vomo, which lies near Waia.

The specimen is a gray porous rock having visible small phenocrysts of pyroxene and feldspar.

The groundmass has a hyalopilitic structure consisting of a dense mat of feldspar rods and augite microlites with magnetite grains cemented by a greenish brown glass. The amount of base is small compared with the phenocryst constituent of the rock.

The pyroxene microlites appear to be wholly augite, as they are non-pleochroic and do not extinguish parallel. The phenocrysts are plagioclase, hypersthene, and augite.

The plagioclase phenocrysts predominate, and most are short rectangular sections and square plates, abundantly filled with zonally arranged brownish glass inclusions which impart a cloudy aspect to the sections. Undulating extinction due to pressure or strain is noticeable in several of the larger plates. The extinction angles on sections normal to the twinning lamellæ reach 33°, showing the presence of a quite basic labradorite. The rods, however, and some of the phenocrysts, show much smaller extinction angles, under 10°, and are probably oligoclase.

The pyroxene phenocrysts are both hypersthene and augite, which are at times intimately associated. The hypersthene occurs in prismatic and basal sections which give the common optical characteristics. The pleochroism is quite marked, although not especially strong; c = bluish green, a = reddish brown, and b = brownish yellow. The plane of the optic axes is 010, and sections parallel to 100 show they are normal to the acute bisectrix, although the optic angle is a little wider than the field of the microscope. The augite is bluish green, exactly matching the color of the hypersthene in the vertical direction. It is non-pleochroic and shows the large extinction angle. One section encloses an irregular core of the pleochroic hypersthene.

This is the only instance where the orthorhombic pyroxene was noted as a constituent of the rocks from this region, yet its presence might be more generally shown from a study of a larger amount of material. There is a noticeable absence of olivine in the rocks of these islands, while on the other hand it is a common constituent of the rocks from all of the volcanic islands lying at a distance to the east of Viti Levu. These eastern islands are composed of rocks decidedly more basic in composition than those from the islands immediately adjacent to the large island of Viti Levu, as will be seen in the descriptions which follow.

Ovalau.

This is a very important island of the group, lying just east and near Viti Levu, but no specimens other than some much decomposed rock from the vicinity of Levuka were collected. The specimens appear to be altered andesites, either hornblende or augite andesites. According to Wichman the prevailing rock is augite andesite, although some hornblende andesite does occur.

Olivine Basalt from Wakaya.

Wakaya is about four miles long, lying nine miles east of Levuka. Its highest peak rises 595 feet above the sea.

The basalt is a dark greenish brown vesicular rock containing amygdaloids of calcite.

Microscopically the rock shows a brown vitrophyric base which has a slight tendency to perlitic structure developed in the consolidation. Long, slim feathery forms of feldspar are scattered through the amorphous base. There are only one or two lath-shaped sections present, and these show by their extinctions that they are labradorite. The phenocrysts are olivine and augite. Olivine occurs in perfect automorphic crystals which are often stained yellowish by the oxide of iron which has resulted from a slight alteration of the olivine. Embayments formed by the groundmass are seen in some of the crystals.

Augite is less than the olivine in amount. It occurs in pale green automorphic crystals, and contains inclusions of the older minerals, olivine and magnetite, besides some glass.

The rock from its mineral composition might be considered a limburgite, yet the large amount of glass base present would doubtless show the rock to be, chemically, a more acidic type of rock than a limburgite.

Olivine Basalt from Makongai.

Makongai is two miles long by one and a half miles wide, lying seven and a half northwest of Wakaya. It has two peaks in the centre, with an average height of 875 feet.

The specimens from this island are too much altered to determine their petrographic characters, but the rock appears to have been like that from Wakaya. Well developed olivine and augite crystals are still preserved in the decomposed base.

Olivine Basalt from Ngau.

The island of Ngau lies twenty-seven miles southeast of Ovalau, and is eleven miles long by four miles wide.

The rock is porous, of a gray color, and under the microscope shows a base composed mainly of stout plagioclase laths, whose angular interspaces are filled with a speckled mixture of bluish green augite microlites, minute feldspathic rods, and magnetite grains, the whole forming an intersertal structure. No glass is however apparent. The feldspathic constituent is limited to the plagioclase laths and rods in the groundmass, and is subordinate to the pyroxene in amount. Albitic twinning combined with the Carlsbad is common, and the extinction angles on sections normal to the twinning planes are those of labradorite, averaging 28°. Most of the phenocrysts are large automorphic augites, the olivine being subordinate in amount and size.

Augite occurs in light green perfect crystals, some of which show a very weak pleochroism to yellowish tones. Zonal structure and twinning is seen in several of the sections. Inclusions of olivine and magnetite are present and some of the sections have been penetrated along the cleavage by the groundmass. Olivine occurs here and there in the slide in rounded grains without any original crystal boundaries, and most of it has altered slightly so as to be coated yellowish brown.

A few anhedrons of magnetite occur, but most of the magnetite is in small grains.

Augite Andesite from Nairai.

Nairai Island is four miles long by one and a half to three miles wide, lying about ten miles east of Ngau.

The rock has a hyalopilitic base, consisting of minute short rods of feldspar with augite grains and magnetite particles in a glass cement. The feldspar phenocrysts which were present have all been altered to a brown carbonate, leaving only the rims of the original mineral. The brown carbonate is apparently calcite stained with the iron oxides, this staining solution saturating a good portion of the groundmass and filling the cavities with banded walls of brownish opalitic material.

Augite occurs in automorphic crystals, which occasionally show twinning parallel to the orthopinacoid. A few grains of olivine can be detected stained reddish brown.

Na Kobu. — This is a peak in a small island of the Nairai group, just off the south coast of the main island.

Specimens of augite andesite were collected from the top and base of the Kobu which show only a slight structural difference. The rock from the top is dark gray and fine-grained. It shows under the microscope a groundmass having a hyalopilitic structure. Feldspathic rods, green augite microlites, and magnetite grains are thickly strewn in a glass base. Some of the feldspars reach dimensions to be called phenocrysts, but in general the porphyritic character of the rock is not marked. The feldspar rods have a distinct parallel flow arrangement.

The pyroxene constituent is only in microlitic form, no phenocrysts occurring.

The specimen from the base of the Kobu is of the same nature as that from the top, but it shows a distinct porphyritic structure, having numerous large phenocrysts of feldspar.

Augite-olivine Andesite from Moalo.

Moalo is a triangular shaped island seven miles long by five miles wide, lying southeast of Viti Levu. The specimen was collected from the Observatory Rocks on the northern coast.

The rock is dark gray, compact, and shows megascopic crystals of augite and olivine in the base.

Microscopically the groundmass has a pilotaxitic structure, and consists of minute uniform-sized crystals of augite and feldspar in distinct flow arrangement, sprinkled with grains of magnetite and some brown grains of olivine.

The groundmass forms the larger part of the rock, and the phenocrysts are mostly augite and olivine.

The few plagioclase phenocrysts give labradoritic extinctions, averaging 27° on sections normal to 010.

The phenocrysts of augite and of olivine are large, the latter predominating in number.

Augite is in good automorphic sections, and contains inclusions of the older olivine. The olivine sections usually have a yellowish brown border enclosing the colorless centres, and the iron oxide has also penetrated along the fractures.

Olivine Basalt from Totoya.

Totoya is a circular island about six miles in diameter, being an extinct volcano with a crater bowl three miles in diameter and a ridge 1,200 feet above the sea. It lies a few miles southeast of Moalo. Specimens

were collected from the top of the ridge, and from the interior of the bowl.

The specimen from the top of the ridge is somewhat decomposed, but resembles the basalt from Wakaya.

The groundmass has a pilotaxitic structure consisting of rather long parallel arranged laths of feldspar and a speckled mixture of augite and feldspar microlites with magnetite and olivine grains. The phenocrysts are labradorite, augite, and olivine.

The rock contains very few large sections of feldspar, most of this constituent appearing as slender laths in the groundmass.

Augite occurs in very large pale green crystals, which are usually much broken up and of irregular form. Zonal structure is well shown. Some of the sections contain areas of rectangular-shaped glass inclusions. These are also seen in the larger feldspar sections.

Olivine is scattered throughout the rock in small corroded grains, with a few fragments of larger phenocrysts. It is all coated reddish brown. From the characteristic yellowish to reddish brown grains in many of these rocks, iddingsite is strongly suggested; yet the coloring matter is in general not homogeneous throughout the grain, the centres often being colorless and showing the high polarization colors of olivine.

Calcite fills several of the cavities as a secondary formation, and usually has a brown border from the presence of much iron oxide. This oxide of iron, which has apparently arisen through the alteration of the olivine, has filled many of the cavities with the same banded layers as previously noted.

The specimen from the interior of the crater has an orthophyric type of groundmass, and the rock is a basaltic lava.

Short rectangular and square sections of feldspar are numerous, between which is a dusty brown glass. No original dark silicate is present, but secondary serpentine is common and in many cases fills the cavities with light yellowish green radiating fibrous bands. Brown limonite is also a frequent filling for these cavities. Large areas of calcite and a few cavities having quartz in them occur.

Olivine Andesite from Kambara.

Kambara is the next island visited, just east of Totoya. It is one of the southern islands of the Lau or Eastern group, and is four and a half miles long by three miles broad.

The hand specimen shows a very fine dark gray holocrystalline rock, with no porphyritic structure apparent.

The groundmass under the microscope is seen to be composed of a film of violet tinged augite microlites and feldspar laths, presenting a very homogeneous structure which can be designated as pilotaxitic. The small augite prisms have rounded ends, and seem fully equal in amount to the feldspar.

The rock lacks phenocrysts of any size. The only mineral present which is plainly of an older crystallization is olivine. This is well disseminated in the rock as small rounded sections whose original crystal boundaries have been lost by corrosion. These sections are not much larger than those of the groundmass. They have the common yellowish to yellowish brown color from the iron staining, and only a few show colorless centres.

A small flake of biotite, which is nearly colorless normal to and deep brown parallel to the polarizer, can be detected here and there in the groundmass.

Augite Andesite Lava from Komo.

Komo is another island of the Eastern group, lying northeast of Kambara. It is very small, one and a half miles long by half a mile wide. The specimen was collected from the shore bluff, and is a black vesicular rock.

The groundmass shows a multitude of short rectangular sections with a less number of augite grains in a brownish amorphous base which is quite dusty from magnetite grains. There is a considerable impregnation of this base by brownish limonitic stains, and the same banded filling of opal in the cavities is noted.

The phenocrysts are in the main large automorphic crystals of labradorite. Many have been corroded by the magma, and most are filled with dark glass inclusions. Some of the sections show alternate zones of clear and cloudy layers.

Augite occurs, but is much inferior to the feldspar in amount. One automorphic crystal has a pleochroic core, yellowish green to brown, which resembles hypersthene, but no other indication of hypersthene was seen in the slide.

Olivine Andesite from Yanu Yanu.

This is a very small island, two hundred feet high, of the Exploring Isles.

The specimen presents a dark gray compact holocrystalline rock. It lacks any definite porphyritic structure, although a few of its constituents

show a different period of crystallization from the groundmass, and reach a size to be designated as phenocrysts.

The groundmass is pilotaxitic, consisting of short green augite microlites, feldspar rods, and magnetite grains. No glass is present in the base.

The feldspar plates show an extinction angle of about 12° normal to 010, which indicates a soda-lime feldspar of an oligoclase or andesine composition.

The larger phenocrysts are olivine. They occur as rounded sections, usually much corroded by the magma, and show alteration to serpentine along the fractures. Crystal sections and anhedrons of magnetite are common.

The above descriptions are made in the form of a report on the individual specimens in the collection, and no generalizations are attempted, because of the lack of sufficient representative material. Notes regarding the appearance and general structure of these volcanic islands are not at hand, consequently the contents of this paper are purely petrographical.

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INVESTIGATIONS ON PERIODICITY IN THE WEATHER.

By H. Helm Clayton.

INVESTIGATIONS ON PERIODICITY IN THE WEATHER

By H. Helm Clayton.

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Investigations on periodicity in the weather have occupied the attention of many workers, and I can refer only in a brief way to investigations along other lines than those on which I have been engaged.

A knowledge of the existence of annual and diurnal periods in the weather is older than history, and the fact that these periods depend on changes in the position of the sun is universally recognized. A large part of the labor of meteorologists at the present time is devoted to determining, for different parts of the world, the amount of change in weather conditions resulting from these periods.

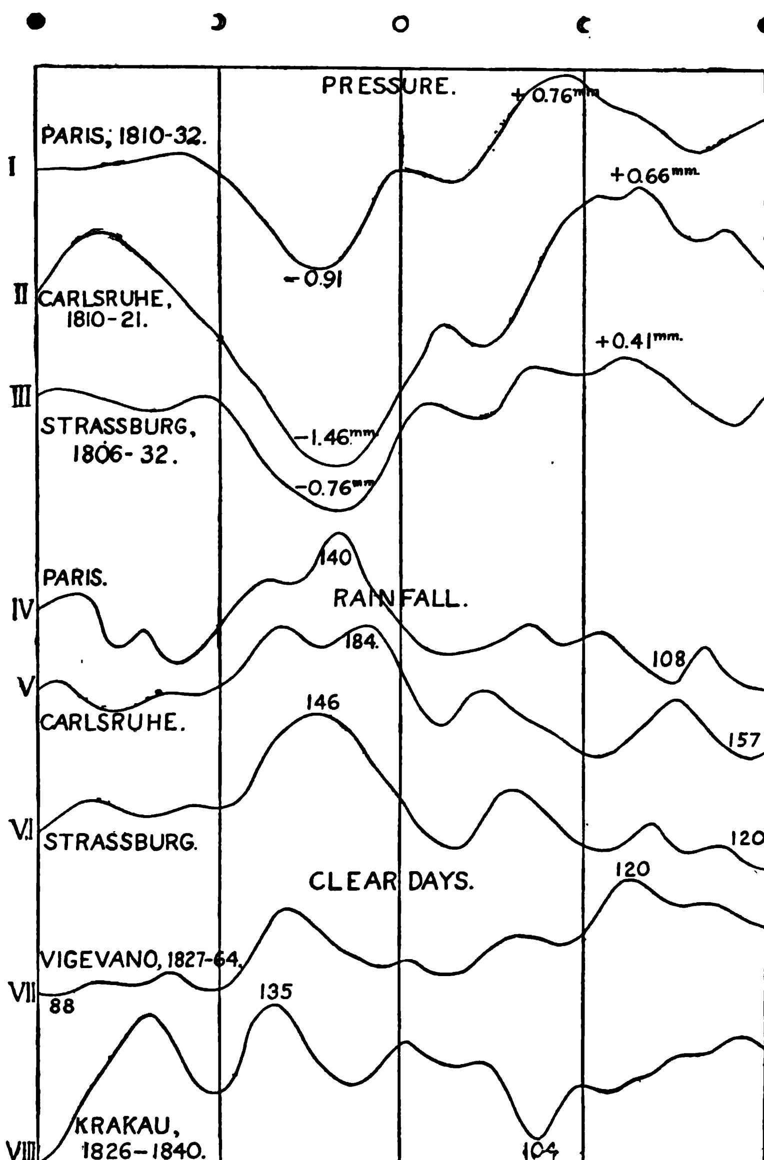
Many investigators have sought to prove a period in terrestrial magnetism and in meteorological phenomena coinciding with the rotation of the sun on its axis. Among these are Broun (Comtes Rendus, 1873), Hornstein (Sitzungsberichte Wien-Ak., 1873), Liznar (Sitzungsberichte Wien-Ak., 1885, '86, '87, and '88), Balfour Stewart (Nature, 1879 and 1884), Nerwander, (Poggendorffs Annalen, Bd. LVIII.), Buys Ballot (Archives Neerlandaises, Tom. XX.), Muller (Mélanges physiques et chemiques, Bull. Ac. St. Pét., 1886), Schmidt (Sitzungsberichte Wien-Ak., 1888), Veeder (Proc. Rochester Acad. Sci., 1889), Hall (Amer. Jour. of Sci., Vol. XLV., 1893), and Bigelow (Amer. Meteor. Jour., 1893). The results of these researches differ from one another, and none has received general acceptance.

Also there has been much study of the relation between the frequency of sun spots and corresponding periods in the weather. The results are conflicting, and the relation is not accepted as proved. The relation if it exists is undoubtedly complex, but this is what might be expected in meteorological phenomena. An excess of rainfall in India implies an increased ascent of air. This demands an increased descent of air in some other part of the world, as for example in Russia. Hence, an excess of rainfall in India would be coincident with a deficiency in Russia, and the two would have opposite phases in regard to the sunspot period,

as is found to be the case. Again, if during sunspot maxima there should be an increase in atmospheric pressure over the Mid-Atlantic, there would be an excess of southwest winds over the British Isles during this time. Since winds in blowing over mountain chains have their moisture condensed, and descend on the other side dry, the above conditions might result during a sunspot maximum in an excess of moisture on one side of a mountain chain and a deficiency on another. Hence, in an area as small as Scotland, opposite weather conditions in different places during the sunspot cycle do not necessarily disprove the existence of the cycle. The results of various investigators from various parts of the world need to be gathered and carefully considered from numerous standpoints, before the weather cycle can be said to be disproved, or before all the phenomena can obtain rational explanation as a result of the cycle.

Next to the sun, the heavenly body which has obtained most attention as a probable cause of weather cycles has been the moon. A popular belief in the influence of the moon on the weather is older than history, and exists in full vigor to-day. The earlier meteorologists, attracted by this general belief, devoted much time to investigating the question of the relation of weather to the moon's position. Considerable data of various kinds were accumulated, to which full references are found in Van Bebber's Handbuch der Witterungskunde. The results given in most detail were plotted by Van Bebber, and are here reproduced in Plate I. from traces made with a pantograph. Curve I. was plotted from the mean atmospheric pressure at Paris for each day of the synodic period of the moon, as obtained by Eugene Bouvard for the twenty-three years 1810–32. Curves II. and III. are the means of the atmospheric pressure at Carlsruhe and Strassburg for each day of the synodic period of the moon, as obtained by O. Eisenlohr for the years 1810–21 and 1806–32, respectively. The three curves are in close agreement, showing a minimum pressure about midway between the first quarter and full moon and a maximum near the last quarter. Curves IV., V., and VI. show the number of rainy days at Paris, Carlsruhe, and Strassburg for each day of the synodic period as worked out by Bouvard and Eisenlohr for the intervals given above. These curves are alike, and show a maximum frequency of rainy days at the time of the minimum of pressure. Curves VII. and VIII. show the number of clear days at Vigevano and Krakau for each day of the synodic period as obtained for the first place by Schiaparelli for the interval 1827–64 and for the second place by Wierzbicki for the interval 1826–40. The curve for Vigevano shows the

PLATE I.


PRESSURE.
+0.76mm
PARIS, 1810-32.
I
+0.66mm
-0.91
II
CARLSRUHE, 1810-21.
+0.41mm
III
STRASSBURG, 1806-32.
-1.46mm
-0.76mm
140
PARIS.
IV
RAINFALL.
184.
108
V
CARLSRUHE.
146
157
VI
STRASSBURG.
120
CLEAR DAYS.
120
VIGEVANO, 1827-64.
VII
88
135
KRAKAU, 1826-1840.
VIII
104

maximum frequency of clear days about the time of the last quarter of the moon, corresponding with the time of maximum pressure at Paris, Carlsruhe, and Strassburg. The curve for Krakau, however, shows the opposite condition. For purposes of comparison Van Bebber collected in tables the results of various investigators. The results showing the relation of the moon's phases to atmospheric pressure are given in Table I., except that two stations where the interval of observation did not exceed five years are omitted. In a large proportion of these results the minimum of barometric pressure is about the time of the moon's second octant and a maximum about the time of the last quarter. The range from maximum to minimum is small, but the stations cover a considerable portion of Europe and there is one as distant as Batavia. The general agreement of the results is surprising in view of the fact that some of the investigators were seeking to disprove the lunar period in atmospheric phenomena, or at any rate were sceptical of its existence. It is improbable that the pressure is high over all the earth at the same time, so that future investigators will probably find opposite phases of the period for different parts of the world.

In Plate II. are curves plotted from the mean temperature for each day of the lunar synodic period. They are drawn by means of a pantograph from curves given by J. Park Harrison in the Proceedings of the Royal Society of May 4, 1865, except No. IV., which I derived from thirteen years' observations at the Blue Hill Meteorological Observatory (1886–98). The curves were plotted from the unsmoothed mean of each day of the period. No. I. is from the daily mean of temperature at Greenwich, Eng., from 1856–64. No. II. is from the minimum temperatures for the same interval at the same place. No. III. is from the daily means of temperature at Oxford, Eng., from 1859–61. No. IV. is from the daily means of temperature at Blue Hill, Mass., from 1886–98. No. V. is from the daily means of temperature at Oust Silosk, Siberia, from 1837–43. The maximum and minimum values are given by numerals printed near the curves. The curves are irregular and the ranges not large, but they all agree in showing a generally higher temperature between new moon and full than between full moon and new. At the European stations the warmest weather seems to be about the first quarter, and the coldest about the last, thus agreeing approximately, either directly or inversely, with the times of maximum found by other investigators for the pressure and for the number of rainy days.

In Plate III. are curves showing the number of thunderstorms on each day of the moon's synodic period. No. I. is plotted from results

TABLE I.

RELATION OF THE MOON'S PHASES TO THE AIR-PRESSURE. (DEPARTURE FROM THE MEAN.)

Author.	Station.	New Moon.	1st Octant.	First Quarter.	2d Octant.	Full Moon.	3d Octant.	Last Quarter.	4th Octant.
		mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Hallaschka . . .	Prag, 1818/27	+0.68	−0.20	+0.34	−1.04	+0.29	−0.88	+0.07	−0.16
Flaggergues . . .	Viviers, 1808/27	−0.05	−0.07	−0.07	−0.72	−0.21	+0.26	+0.88	+0.04
Bouvard	Paris, 1810/32	+0.06	−0.21	+0.11	−0.74	−0.21	−0.09	+0.76	+0.49
Eisenlohr . . .	Paris, 1819/40	+0.14	−0.24	−0.11	−0.11	+0.06	−0.08	+0.30	+0.03
" . . .	Carlsruhe, 1810/21	+0.16	+0.69	−0.09	−1.38	−0.75	−0.55	+0.91	+0.78
" . . .	Strassburg, 1806/32	+0.27	−0.02	−0.05	−0.82	+0.39	+0.22	+0.44	−0.02
Mädler	Berlin, 1820/35	+1.10	. . .	+0.67	. . .	−0.09	. . .	−0.02	. . .
Lüdicke	Gotha, 1867/75	+0.39	. . .	−0.50	. . .	−0.57	. . .	+0.68	. . .
Streintz	Greenwich, 1848/67	−0.40	−0.02	+0.46	+0.03	−0.39	−0.51	+0.03	+0.76
Bergsma	Batavia, 1866/80	−0.11	+0.00	−0.01	−0.00	+0.03	+0.04	+0.09	−0.03

PLATE II.

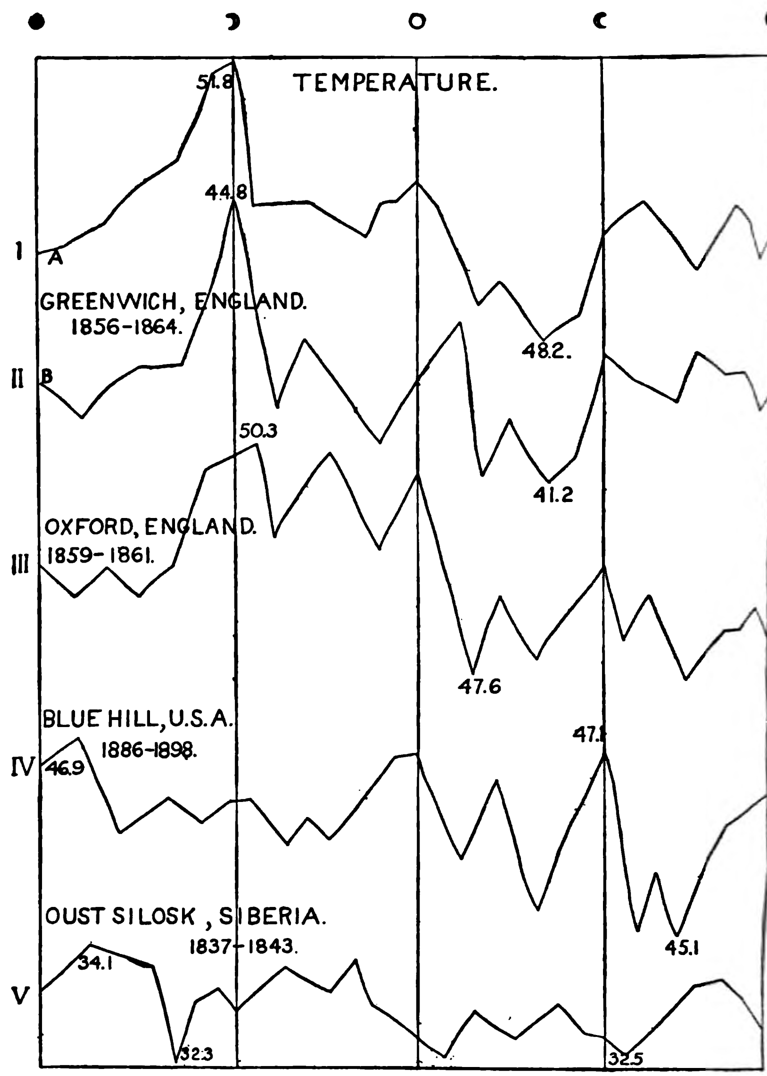
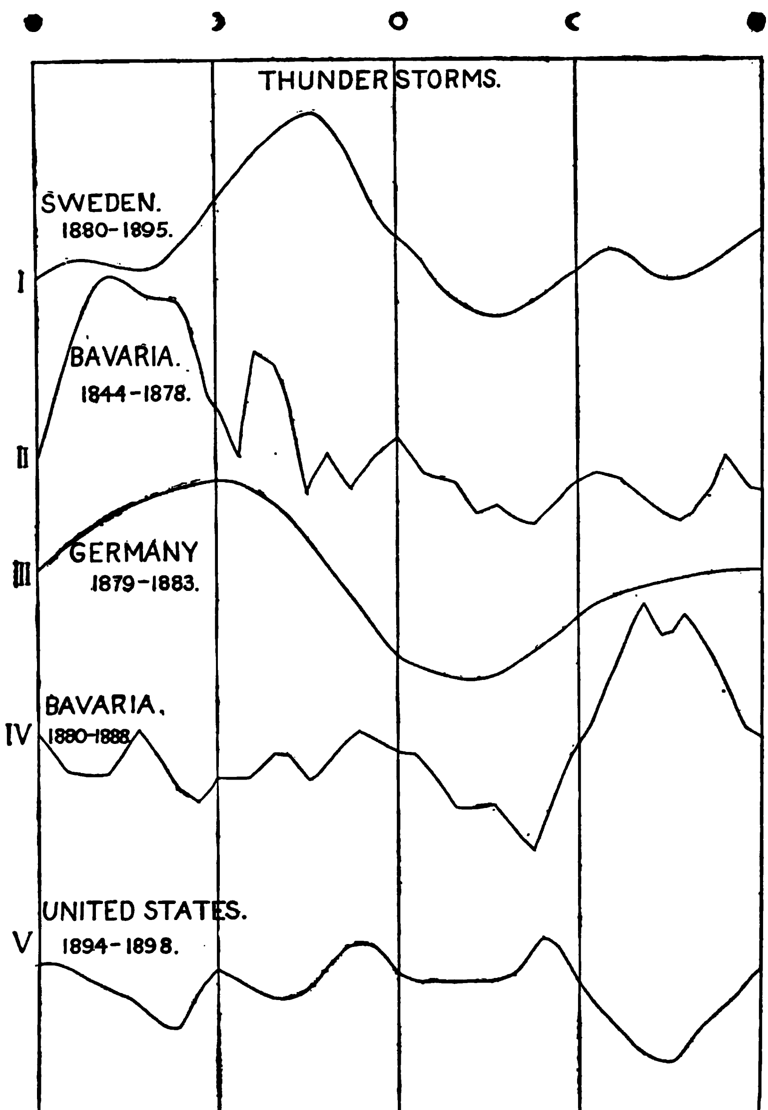

TEMPERATURE.
51.8
44.8
I
A
GREENWICH, ENGLAND.
1856-1864.
48.2.
II
B
50.3
41.2
OXFORD, ENGLAND.
1859-1861.
III
47.6
BLUE HILL, U.S.A.
1886-1898.
IV
46.9
47.1
OUST SILOSK, SIBERIA.
1837-1843.
45.1
34.1
V
32.3
32.5

PLATE III.



THUNDERSTORMS.
SWEDEN.
1880-1895.
I
BAVARIA.
1844-1878.
II
GERMANY
1879-1883.
III
BAVARIA.
1880-1888
IV
UNITED STATES.
1894-1898.
V

obtained by Dr. Ekholm and Mr. Arrhenius from the thunderstorms observed throughout Sweden in 1880–95. The unsmoothed results give a decided maximum of thunderstorms (50 per cent above the mean) on the third day after the first quarter, and a minimum (34 per cent below the mean) three days before the last quarter. But the plotted curve is irregular and the curve given here is plotted from the results smoothed by a process described in the pamphlet "Ueber den Einfluss des Mondes auf die Polarlichter und Gewitter, von Nils Ekholm und Svante Arrhenius" (Swedish Academy of Science, 1898). No. II. shows the number of lightning strokes which were recorded in Bavaria from 1844–78 as determined by E. Wagner for each day of the moon's synodic period (Meteorologische Zeitschrift, August, 1889). No. III. is from the number of thunderstorms found in Germany by Dr. Koeppen for each quarter of the moon from 1879–83 (Meteorologische Zeitschrift, January, 1885), A smooth curve is plotted through the numbers at each quarter. No. IV. is plotted from the number of thunderstorms in Bavaria found by E. Wagner for each day of the synodic period from 1880–88. Before plotting, the numbers were smoothed by taking the mean of each five. No. V. was plotted from the total number of thunderstorms on each day of the period from 1894–98, determined for me by Mr. A. E. Sweetland. The results were reduced to percentages, and smoothed by getting the second mean of each successive two before plotting. The range is from +8 to −12 per cent of the mean.

The well known meteorologist Luke Howard was much interested in the question as to whether there was a period in the weather corresponding to the tropical period of the moon, or to the time of its movement back and forth across the plane of the earth's equator. From a careful study of the observations made in the vicinity of London, for the eighteen years from 1815–32, he arrived at the conclusion that the most rain (by measure at the earth's surface) falls in the weeks when the moon is south of the equator and least when it is passing over the equator southward, the full north declination and the week during which it is approaching the equator having a mean quantity. "On investigating the connection of rain with thunder he finds that the atmosphere of our climate is sensibly more subject to electrical accumulation in the clouds and to the consequent changes when the moon is either south of the equator or returning from that position." From his studies of the air temperature he deduces the following conclusions: "(1) That the pressure of an atmospheric tide which attends the approach of the moon to these latitudes, raises the mean temperature 0.35 of a degree. (2) That the

rarefaction under the moon in north declination lowers the temperature 0.13 of a degree. (3) That the northerly swell following the moon as she recedes to the south further cools the air 0.18 of a degree. (4) That this cold continues while the moon is away south, reducing the mean temperature yet lower by 0.04 of a degree." (Papers on Meteorology, etc., by Luke Howard, F. R. S., London, 1854, p. 44.) In showing the greatest number of thunderstorms when the moon is south, Howard's results agree with the later ones of Dr. Ekholm and Arrhenius and of Mr. Sweetland and myself. M. P. Garrigou Lagrange of the Observatoire Physique et Météorologique, at Limoges, France, investigated the relation between the moon's change in declination and the change in the pressure of the atmosphere over the northern hemisphere, using for this purpose the international observations of 1882–83. His conclusions as communicated to the Société Météorologique de France are: — (1) In the atmosphere of the northern hemisphere there exists an oscillation from one side to the other of about the 30th parallel synchronous with the movement of the moon in declination and of such a nature that when the moon is north the pressure is lower below the 30th parallel and higher above it, and inversely when the moon is south. (2) The gradients show correlative modifications. The barometric slope from latitude 30° toward the south and toward the north is alternately raised and lowered, being steepest below 30° when the moon is north and less steep above 30° and inversely when the moon is south. (3) These differences in the pressure and the gradients increase in proportion as one advances toward the pole, at least as far as the 70th parallel. (4) These movements are superposed on the more general movements which they strengthen or weaken as they are in the same or in a contrary direction.

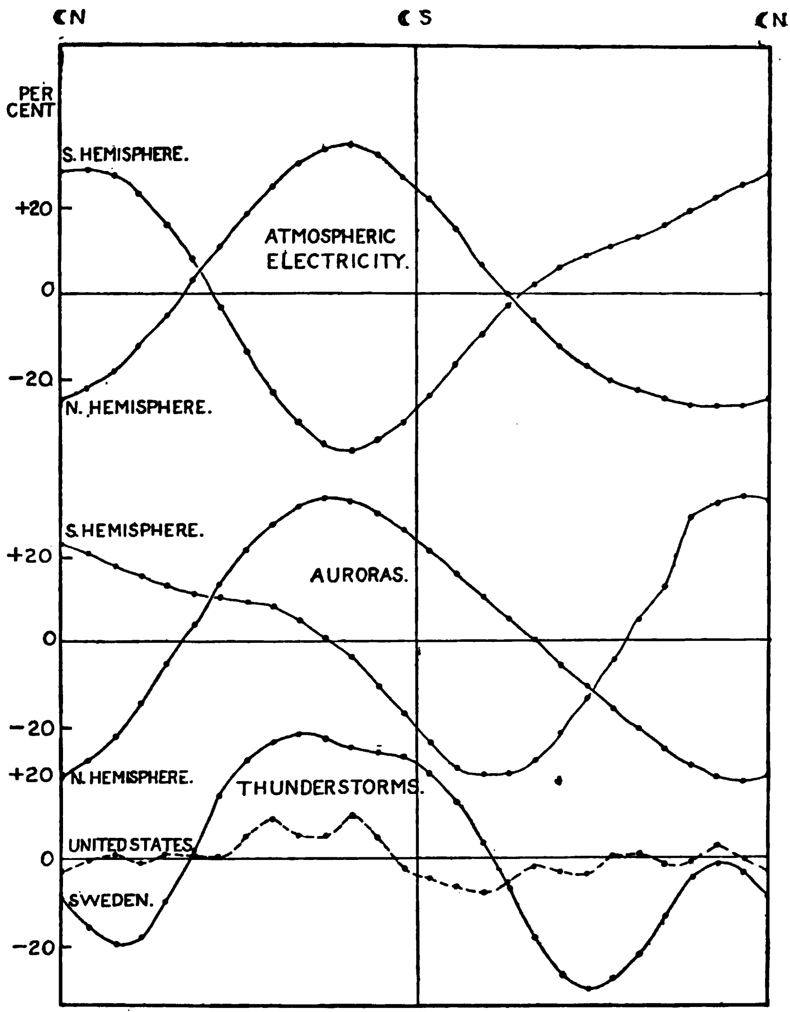
In 1894, Dr. Nils Ekholm and Svante Arrhenius published an investigation on the relation between the electrical potential of the air and the position of the moon in declination. (Ueber den Einfluss des Mondes auf den Electrischen Zustand der Erde, Bihang till K. Svenska Vet. Akad. Handlingar, Band XIX., Afd. I., No. 8, Stockholm, 1894.) They found that in the northern hemisphere the difference in potential between the earth and air was greatest when the moon was in southern declination while in the southern hemisphere it was greatest when the moon was in northern declination, the variations being 20 per cent or more above and below the mean. In Plate IV. the curves marked "Atmospheric Electricity" show the results for Cape Horn and Cape Thordsen (Spitzbergen). The curve marked "S. Hemisphere" is for Cape Horn; the one marked "N. Hemisphere" is for Cape Thordsen. The explanation

suggested for this phenomenon was that the moon is negatively electrified like the earth, and, acting by induction on the earth's surface, diminishes the electrical potential on the portion of the earth nearest the moon and increases the potential on the opposite side of the earth. In 1896–97, from observations made throughout the United States, I investigated the relation of the frequency of auroras to the moon's position in declination, and found the greatest number of auroras when the moon was in south declination. (Paper read before the Boston Sci. Soc., May 11, 1897. See Boston Evening Herald of May 12, 1897, and Amer. Jour. of Science of February, 1898.)

In 1898, Dr. Ekholm and Mr. Arrhenius published an exhaustive and most careful research on the relation of auroral frequency to the position of the moon in declination, in which the various sources of error which might influence the results were considered and eliminated. (Ueber den Einfluss des Mondes auf die Polarlichter und Gewitter, von Nils Ekholm and Svante Arrhenius, Bihang der k. schwedischen Akad. d. Wissenschaften, 1898.) They made use of all the available observations both in the northern and southern hemispheres. Their results from all the observations in each hemisphere are plotted in the curves marked auroras in Plate IV. The curves are nearly opposite in phase, and clearly follow the same course as that of atmospheric electricity shown in the upper part of the same plate. Ekholm and Arrhenius also determined the frequency of thunderstorms in Sweden as related to the moon's position in declination, and their results are plotted and marked thunderstorms in Plate IV. The frequency follows the same course as that of the auroras and of the amount of atmospheric electricity except that there is a secondary maximum about the time of the moon's greatest northern declination, a phenomenon which I found also for auroras in the United States. From the observations in the United States published in the Monthly Weather Review, Mr. A. E. Sweetland worked out for me the frequency of thunderstorms as related to the moon's position in declination and obtained the results plotted in the broken curve marked United States. The range is very small but the curve follows a similar course to the one for Sweden showing a maximum a few days preceding the greatest northern declination.

My work in meteorology was instigated by the popular belief in the influence of the moon on the weather. The general prevalence of this belief led me when a youth to investigate whether the weather conditions supposed to follow certain positions of the moon really did so. I found the subject a complex one, and, taking up the study of modern mete-

PLATE IV.


☾N
☾S
☾N
PER CENT
S. HEMISPHERE.
+20
ATMOSPHERIC ELECTRICITY.
0
−20
N. HEMISPHERE.
S. HEMISPHERE.
+20
AURORAS.
0
−20
+20
N. HEMISPHERE.
THUNDERSTORMS.
UNITED STATES.
0
SWEDEN.
−20

orology, I adopted the general belief of meteorologists that, as there was no rational reason why the moon should influence the weather, it probably did not. I had, however, in my investigation found evidence of periodic changes in the weather independent of the annual and diurnal periods. I decided to lay aside any theory as to their cause, and to determine as definitely as possible the lengths, ranges, and methods of oscillation of the periodic changes. My investigations led me to the following conclusions which I believe are important: — (1) That every weather period is rendered complex by the existence of periods which bear the relation of harmonics to the primary, that is, their lengths are twice, one half, one third, one fourth, etc., the length of the primary. (2) The periods in different parts of the world have different phases, as for example in the annual period it is cold in the northern hemisphere when it is warm in the southern, and in the sunspot period it is dry in Russia when it is wet in India. (3) At any given place on the earth's surface the harmonics, and in some cases the primaries, reverse in phase. In the case of some of the longer periods this has been traced to a movement of the centre of oscillation from place to place. (4) At any given place the periods and their harmonics do not vary synchronously. Sometimes the primary period is weak, while one or more of the harmonics are strong, and the reverse.

One of my earliest investigations, made in 1882–84, was concerning a period of about two years which I now believe is a periodic change in the weather, arising from the annual period, and having twice its length. The results were published in the American Meteorological Journal for August, 1884, and April, 1885. Some of the diagrams are here reproduced. The continuous curve in Plate V. was obtained by taking the average of the monthly barometric means for each twelve consecutive months from 1874 to 1881. The dotted curve was obtained by taking the mean of each consecutive twenty-five months. The dotted and broken curves in Plate VI. were obtained in the same way for the rainfall. In each case the annual period is eliminated, and the unbroken curves show secondary oscillations in pressure and rainfall with about two years between each maximum and minimum.

That the same oscillation prevailed in the temperature is shown by Table II., page 613, giving the departures from the average temperature.

On the eastern coast of the United States the oscillations in pressure were found to be opposite in phase to those over the interior. A table was made showing the departures from the average of twenty-five months at the times of the maxima and minima of the waves. These

PLATE V

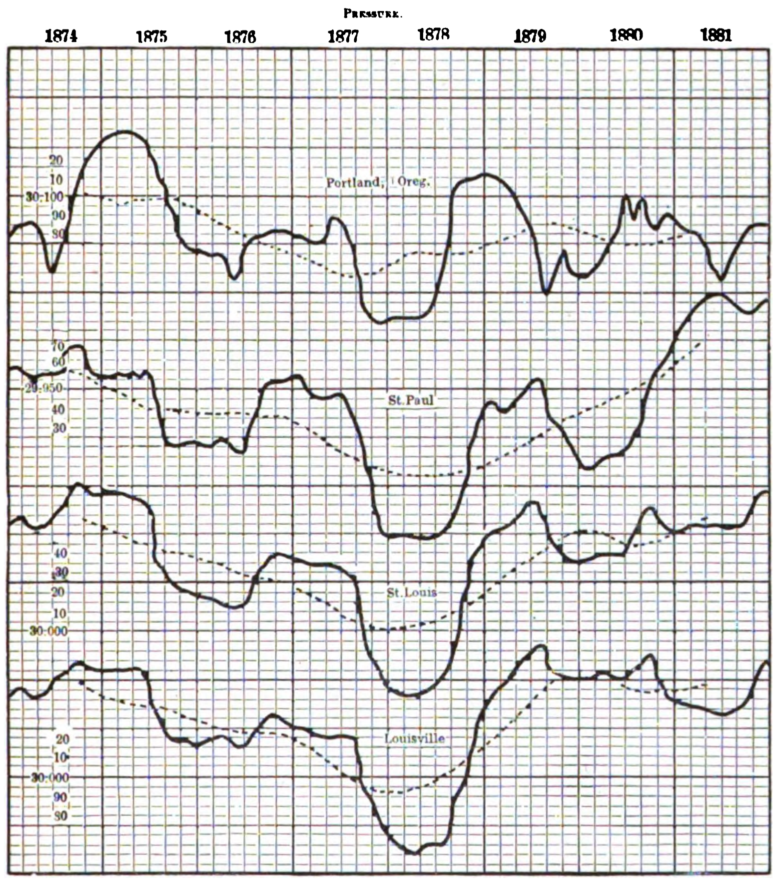

PRESSURE.
1874
1875
1876
1877
1878
1879
1880
1881
Portland, Oreg.
20
10
30.100
90
80
St. Paul
70
60
29.950
40
30
St. Louis
40
30
20
10
30.000
Louisville
20
10
30.000
90
80

PLATE VI.

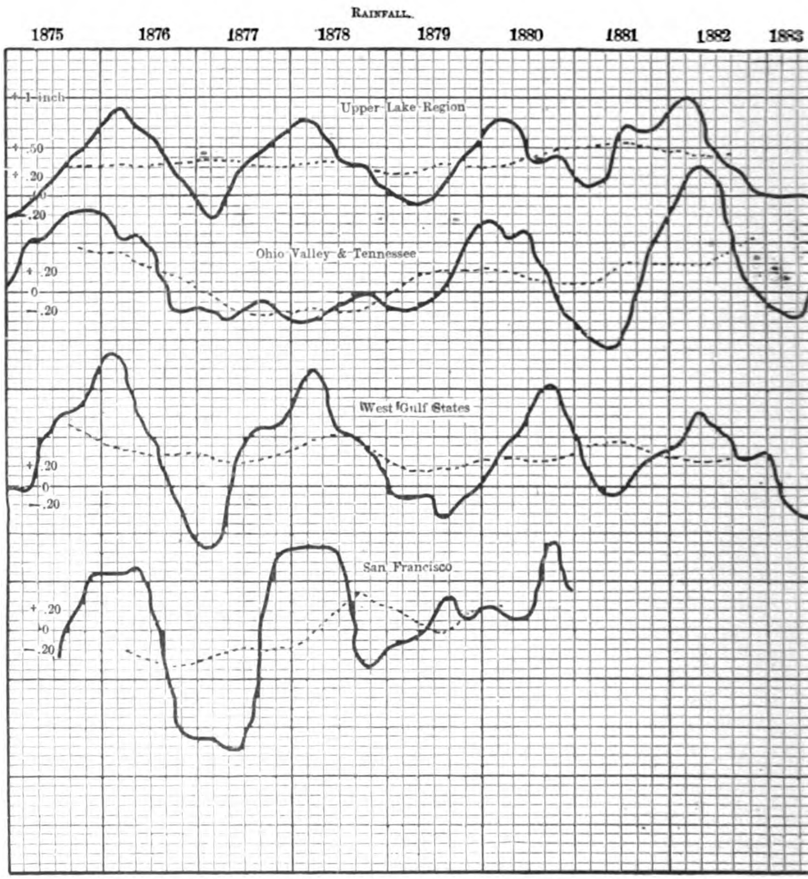
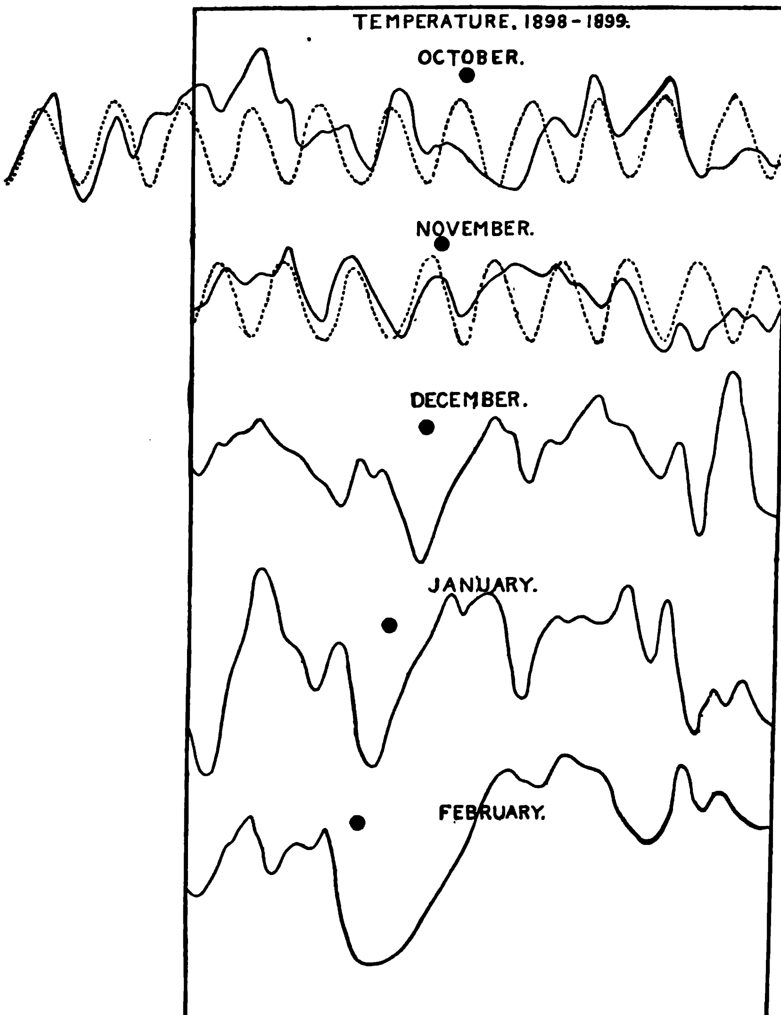

RAINFALL.
1875
1876
1877
1878
1879
1880
1881
1882
1883
+ 1 inch
Upper Lake Region
+ .50
+ .20
.20
Ohio Valley & Tennessee
+ .20
0
— .20
West Gulf States
+ .20
0
— .20
San Francisco
+ .20
0
— .20

PLATE IX.


TEMPERATURE, 1898 - 1899.
OCTOBER.
NOVEMBER.
DECEMBER.
JANUARY.
FEBRUARY.

differences between them. An excess of temperature when the moon was south was indicated by a plus sign, and a deficiency by a minus sign. Dividing the year into thirteen lunations, averages of these differences were obtained for each lunation with the following results: —

	Jan.	Feb.	March.	April.	May.	May-June.	June-July.
1815–23	−4.1	+2.2	−2.6	−1.9	−3.8	−1.8	+0.4
1824–32	+2.4	−2.9	−0.4	−3.8	−2.5	−2.6	−3.6
1815–32	−0.8	−0.4	−1.5	−2.9	−3.2	−2.2	−1.1

	July-Aug.	Aug.	Sept.	Oct.	Nov.	Dec.
1815–23	−1.0	+0.8	+2.9	+0.3	+4.3	+4.3
1824–32	+1.8	+1.6	+1.1	+3.6	+0.7	−0.2
1815–32	+0.4	+1.2	+2 0	+2.0	+2.5	+2.0

These figures indicate that, when the sun is moving from south to north declination, January to June, the air averages colder when the moon is south than when north of the equator; on the other hand, when the sun is moving from north to south declination, July to December, the air averages warmer when the moon is south. The greatest average differences are about 3° F., and occur near the first of May and November respectively, about six weeks after the equinoxes. There are other periods in the reversals of phase, but to recount the numerous methods by which I have tried to isolate them and to determine their length would be tedious and unnecessary, as the results are as yet undeveloped.

Proceedings of the American Academy of Arts and Sciences.

VOL. XXXIV. NO. 23.—JUNE, 1899.

PROCEEDINGS OF THE ACADEMY, 1898–1899.

A TABLE OF ATOMIC WEIGHTS. BY THEODORE WILLIAM RICHARDS.

REPORT OF THE COUNCIL: BIOGRAPHICAL NOTICES.

JUSTIN WINSOR. BY A. LAWRENCE LOWELL.

SAMUEL ELIOT. BY BARRETT WENDELL.

JULES MARCOU. BY ALPHEUS HYATT.

THEODORE LYMAN. BY HENRY P. BOWDITCH.

LIST OF THE FELLOWS AND FOREIGN HONORARY MEMBERS.

STATUTES AND STANDING VOTES.

INDEX.

(TITLE PAGE AND TABLE OF CONTENTS.)

PROCEEDINGS.

Nine hundredth Meeting.

MAY 11, 1898. — ANNUAL MEETING.

Vice-President LOWELL in the chair.

In the absence of the Secretaries, John Trowbridge acted as Corresponding Secretary and Edwin H. Hall as Recording Secretary.

The Report of the Council was read.*

The Treasurer presented his annual report, of which the following is an abstract: —

GENERAL FUND.

Receipts.

Balance, May 1, 1897			$1,961.73
Assessments	$1,005.00		
Sale of publications	238.86	$1,241.86	
Income from investments		4,663.82	
Return of bank tax		40.00	
Legacy of Hon. John Lowell		3,000.00	
Donations		105.00	9,050.68
			$11,012.41

Expenditures.

General expenses	$2,026.00	
Publishing expenses	1,365.31	
Library expenses	1,139.15	$4,530.46
Investments		3,000.00
Balance, April 30, 1898		3,481.95
		$11,012.41

* See Proceedings, Vol. XXXIII. p. 517.

RUMFORD FUND.

Receipts.

Balance, May 1, 1897		$3,133.66
Income	$2,366.25	
Return of bank tax	94.04	2,460.29
		$5,593.95

Expenditures.

Books and binding	$94.10	
Publishing	59.91	
Investigations	1,651.50	
Rent	10.00	$1,815.51
Investment		2,000.00
Balance, April 30, 1898		1,774.84
		$5,593.95

WARREN FUND.

Receipts.

Balance, May 1, 1897	$870.95
Income	855.00
	$1,725.95

Expenditures.

Investigations	$800.00
Balance, April 30, 1898	925.95
	$1,725.95

BUILDING FUND.

Receipts.

Balance, May 1, 1897	$773.78
Income	494.36
	$1,268.14
Balance, April 30, 1898	$1,268.14

The Librarian presented his annual report, of which the following is an abstract: —

2,751 books and pamphlets have been added to the library during the past year, of which 2,089 were obtained by gift and exchange, 513 purchased with the appropriation from the

income of the General Fund, at a cost of $336.25, and 149 with the appropriation from the income of the Rumford Fund, at a cost of $23.92. 224 volumes were bound at an expense of $331.95, of which $32.75 was charged to the Rumford Fund. 185 volumes were borrowed from the Library by 33 persons, of whom 24 were Fellows of the Academy.

The following reports were also presented: —

Report of the Rumford Committee.

At the last Annual Meeting of the Academy the sum of $1,000 was placed at the disposal of the Rumford Committee for use in aid of investigations to which the Rumford Fund may properly be applied.

During the past year appropriations from this have been made as follows: —

(1) To Professor George E. Hale, Director of the Yerkes Observatory, $400, to meet in part the expense of the construction of a large spectro-heliograph.

(2) To Professor A. G. Webster, of Clark University, $250, for the construction of an electrically governed revolving mirror.

(3) To the same, $100, for an investigation upon the Zeeman effect.

(4) To Professor A. A. Michelson, of the University of Chicago, $250, to meet the cost of constructing a new form of interference spectrometer. To this appropriation an additional amount of $250, from the Rumford Fund, was added by vote of the Academy at its March meeting, on recommendation of the Committee.

(5) In addition to these, at the request of the Committee, the Academy at its January meeting voted to grant the sum of $400, from the Rumford Fund, to Professor W. C. Sabine, of Harvard University, for a research on ultra-violet radiations.

In response to a request sent to these and other recent grantees, asking for information as to the progress of the researches to which aid had been rendered, replies have been received as follows: —

Professor Hale writes: "I have at last succeeded in obtaining two Voigtländer portrait lenses of 6½ in. aperture, which are to serve as the principal optical parts of the spectro-heliograph. These lenses, which now cost $600 each, were purchased for $185 each. The balance of the $400 appropriation is to be used in paying an instrument maker who will be employed in constructing the spectro-heliograph.

I have engaged for this purpose the most skilful instrument maker we ever had at the Observatory, and feel certain that he will build a most satisfactory instrument. The large 60° prisms (4 in. on an edge and 6¼ in. high) have already been obtained, and as I am now engaged in making the drawings of the spectro-heliograph, we may reasonably hope that it will be ready before many months have elapsed."

Professor Hale adds, "I feel very grateful to the Rumford Committee for rendering possible the construction of an instrument which should certainly give valuable results when employed with the 40-inch telescope."

Professor Webster writes as follows regarding (2). The "appropriation of $250 for a revolving mirror has not been drawn upon. I have made various experiments to determine the power required, and the friction of bearings of various sorts, and expect to have the instrument constructed during the summer vacation."

Regarding (3) he writes: "The intention was to apply Michelson's method of the interferometer, using however an instrument to measure the visibility, instead of depending, as has hitherto been done, upon eye estimates. On considering the relative advantages of the bolometer, the radiomicrometer, and the radiometer, the last named instrument appeared to be the most convenient, and was therefore chosen. Most of the time has been spent in constructing and experimenting with the radiometer, with the result that, if the instrument was made sensitive enough to measure the quantities involved, its zero was constantly changing, and the instrument was altogether too slow for the purpose. The glass plates of the interferometer also absorbed such a large fraction of the radiation that the method would have been impracticable, without fluorite plates, which would have entailed a large expense. We have therefore reluctantly been obliged to give up work on the Zeeman effect, and the money will be returned."

Professor Michelson writes that his paper read at the April meeting of the Academy may be considered as a report of progress of his investigation, the "echelon spectroscope" there shown being the first made instrument of its kind. The amount of the appropriation still unexpended, about $300, will be applied to the construction of a larger instrument of the same character.

Professor Sabine states that the camera made for his investigation by Clark and Sons has barely been completed within the past few days, under which circumstances it has not yet been possible to begin experimental work.

Statements have also been received from persons to whom recent appropriations have been granted, but prior to May, 1897, as follows:—

Professor B. O. Peirce, of Harvard University, was granted an appropriation of $200 in 1892, and a further appropriation of $250 in 1895, for researches upon the thermal conductivity of rocks and other poor conductors. A preliminary paper has been published in the American Journal of Science, with the consent of the Rumford Committee, and also a table of roots of a Bessel Equation, in the Bulletin of the American Mathematical Society. The cost of the investigation, which has proved to be a very laborious one, has greatly exceeded the amount of the grant. It is expected to publish the final results in the near future.*

Professor F. A. Laws, of the Massachusetts Institute of Technology, was granted $300 in 1894, to aid in an investigation of the thermal conductivity of metals by a new method proposed by him. The research was delayed for a time, but is now in active progress, and it is probable that numerical results will be secured very soon. The unexpended balance of the appropriation will be applied to the determination of the conductivities of other metals.

Professor E. L. Nichols, of the Cornell University, received in 1894 a grant of "a sum not exceeding $500" (on the authorization of the chairman) in aid of a study of the emissive power of carbon at different temperatures. Professor Nichols reports that absence from the country for a year, and various unforeseen difficulties have delayed progress, although much time has been spent on preliminary work. The expenses of the research are only in part met by the appropriation from the Rumford Fund, of which about $200 has been expended.

Professor Edwin H. Hall, of Harvard University, received a grant of $250 in 1895, in aid of an investigation on the thermal conductivity of metals. The research thus aided was embodied in part in a paper presented to the Academy on January 8, 1896, on the "Thermal Conductivity of Mild Steel." A second paper relating to the thermal conductivity of cast iron is likely to be ready for publication during the coming summer.† There is at present an unexpended balance of $120.

Professor A. G. Webster received a grant of $250 in 1895, for a research on the velocity of electrical waves. Regarding this research Professor Webster says: "A part of the money has been expended partially to defray the expense of the construction of a machine for measuring the interval between the rupture of two electrical contacts, which is

* See Proceedings, Vol. XXXIV. No. 1. † Ibid., No. 11.

the main apparatus used. I have undertaken to attain an accuracy up to one ten-millionth of a second, and the experiments already made encourage me to believe that I shall succeed. On account of the mechanical difficulties involved by the high speeds used, the apparatus has had to be changed a great many times, and the work has been very intermittent. The apparatus is therefore not yet completed, but I hope it will be by summer, when I shall be able to complete the experiments. The sum of about $100 remains unexpended, but will be required before the experiments are completed."

Professor Henry Crew, of the Northwestern University, was granted $400 in 1896, to aid a research upon the arc-spectra of metals. A paper embodying in part the results of this research, entitled "Sources of Luminosity in the Electric Arc," was recently presented to the Academy, and is now in press.* An unexpended balance of $29.84 will be employed in the prosecution of further research in the same general direction.

Mr. R. O. King, then of Harvard University, received a grant of $100 in 1896, for aid in a research upon the "Thomson Effect in Metals." A paper embodying the results of the research thus aided, and entitled "The Thomson Effect in Copper," was presented to the Academy by Professor E. H. Hall at its meeting in April, 1898. A balance of about $10 remains unexpended.

It was voted by the Committee, at a meeting held March 9, 1898, that the Academy at its Annual Meeting be asked to appropriate the sum of $1,000, as in previous years, to be expended under the direction of the Committee in furthering investigations in Light and Heat.

The Committee has also considered at length the question of an award of the Rumford Medal. The claims of various investigators and inventors have been considered with great care, and more than one among them appeared to be deserving of such recognition. After prolonged consideration, the Rumford Commitee has voted at two separate sessions, in accordance with long established custom, to recommend to the Academy an award of the medal to Professor James E. Keeler, now Director of the Lick Observatory, for his application of the spectroscope to astronomical problems, and especially for his investigations of the proper motions of the nebulæ, and the physical constitution of the rings of the planet Saturn, by the use of that instrument.

CHARLES R. CROSS, *Chairman.*

May 11, 1898.

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* See Proceedings, Vol. XXXIII. No. 18.

Report of the C. M. Warren Committee.

In behalf of the C. M. Warren Committee, I have to report that at the last Annual Meeting of the Academy the sum of $600 from the income of the Warren Fund was granted to Professor C. F. Mabery, of Cleveland, in furtherance of his researches on the composition of petroleums. A letter from Professor Mabery, dated March 23, 1898, gives a clear idea of the present condition of his work.

With regard to other grants from the Warren Fund, now outstanding, viz ., those to Professor Phillips of Allegheny City for the investigation of natural gas, and to Professor Hofman of Boston for work on the fusibility of slags, there are good reasons for believing that satisfactory progress is being made by both these chemists.

F. H. Storer, *Chairman.*

May 11, 1898.

Report of the Committee of Publication.

The publications of the past year consist of four numbers of Vol. XXXII., and the first seventeen numbers of Vol. XXXIII., of the Proceedings, aggregating 464 pages and 9 plates.

Only one of these numbers was printed at the charge of the Rumford Fund. The others have cost $1,365.31. The appropriation for publications made by the Academy from its General Fund in May last was $2,100, leaving an unexpended balance of $734.69, to which must be added $236.86 from the sales of the year, or a total balance of $971.55.

The Committee hopes that at least the greater part of this may be added to the ordinary annual appropriation of $1,800, as some unusual expenditures are looked for.

Samuel H. Scudder, *Chairman.*

May 11, 1898.

On the recommendation of the Committee of Finance it was

Voted, To make the following appropriations from the income of the General Fund for the ensuing year: —

For general expenses	$1,500.00
For the Library	1,600.00
For publishing	2,500.00

Voted, That the assessment for the ensuing year be five dollars.

On the recommendation of the Rumford Committee it was

Voted, That one thousand dollars ($1,000) from the income of the Rumford Fund be placed at the disposal of the Rumford Committee to be expended in aid of investigations on Light and Heat, payments to be made on the order of the Chairman of the Committee.

Voted, To award the Rumford Premium to James Edward Keeler, for his application of the spectroscope to astronomical problems.

On the recommendation of the C. M. Warren Committee it was

Voted, That the sum of six hundred dollars ($600.00) from the income of the Warren Fund be granted to Professor Charles F. Mabery, of Cleveland, Ohio, for the continuation of his researches on petroleums.

Voted, That the sum of thirty dollars ($30.00) from the income of the Warren Fund be granted to Professor H. O. Hofman of Boston, for the continuation of his research on the composition and fusibility of slags.

The annual election resulted in the choice of the following officers and committees: —

ALEXANDER AGASSIZ, *President.*
JOHN TROWBRIDGE, *Vice-President for Class I.*
ALPHEUS HYATT, *Vice-President for Class II.*
AUGUSTUS LOWELL, *Vice-President for Class III.*
SAMUEL H. SCUDDER, *Corresponding Secretary.*
WILLIAM WATSON, *Recording Secretary.*
ELIOT C. CLARKE, *Treasurer.*
HENRY W. HAYNES, *Librarian.*

Councillors.

EDWIN H. HALL,
HENRY TABER,
THEODORE W. RICHARDS, } of Class I.

BENJAMIN L. ROBINSON,
WILLIAM T. COUNCILMAN,
JOHN E. WOLFF, } of Class II.

JOHN E. HUDSON, BARRETT WENDELL, EDWARD ROBINSON, of Class III.

Member of the Committee of Finance.

AUGUSTUS LOWELL.

Rumford Committee.

ERASMUS D. LEAVITT, AMOS E. DOLBEAR, EDWARD C. PICKERING, ARTHUR G. WEBSTER, CHARLES R. CROSS, THEODORE W. RICHARDS, THOMAS C. MENDENHALL.

C. M. Warren Committee.

FRANCIS H. STORER, HENRY B. HILL, CHARLES L. JACKSON, LEONARD P. KINNICUTT, SAMUEL CABOT, ARTHUR M. COMEY, ROBERT H. RICHARDS.

The Chair appointed the following standing committees: —

Committee of Publication.

SAMUEL H. SCUDDER, SETH C. CHANDLER, CRAWFORD H. TOY.

Committee on the Library.

AMOS E. DOLBEAR, G. STANLEY HALL, SAMUEL HENSHAW.

Auditing Committee.

HENRY G. DENNY, JOHN C. ROPES.

The following gentlemen were elected members of the Academy: —

Robert DeCourcy Ward, of Boston, as Resident Fellow in Class II., Section 1 (Geology, Mineralogy, and Physics of the Globe).

Francis Cabot Lowell, of Boston, as Resident Fellow in Class III., Section 1 (Philosophy and Jurisprudence).

George Lyman Kittredge, of Cambridge, as Resident Fellow in Class III., Section 4 (Literature and the Fine Arts).

George Howard Darwin, of Cambridge, as Foreign Honorary Member in Class I., Section 1 (Mathematics and Astronomy), in place of the late James Joseph Sylvester.

Nine hundred and first Meeting.

OCTOBER 12, 1898. — STATED MEETING.

VICE-PRESIDENT HYATT in the chair.

The Chair announced the death of Samuel Eliot, Resident Fellow in Class III., Section 3; James Hall, Associate Fellow in Class II., Section 1; Thomas McIntyre Cooley, Associate Fellow in Class III., Section 1; William Ewart Gladstone, Foreign Honorary Member in Class III., Section 3.

The Corresponding Secretary read letters from G. L. Kittredge, Francis C. Lowell, F. Brunetière, G. H. Darwin, and Alb. Heim, acknowledging their election into the Academy; from Alexander Agassiz, announcing his resignation as Director and Curator of the Museum of Comparative Zoölogy at Cambridge; from the Royal Academy of Sciences of Turin, announcing the death of Carlo Giacomini and of Giuseppe Gebelli; from the Polish Association for the Promotion of Medical and Natural Knowledge, in reference to the exclusion of Poles from its meeting at Posen; from the Physico-economical Society at Königsberg, stating the subjects and conditions of award of certain prizes; from August Dauber, of Bochum, calling attention to Professor Edward Buchner's experiments made in Berlin; and from W. Potter, of Victoria, soliciting subscriptions to the Baron von Müller's grave monument fund.

A communication from the Department of State, announcing the date of the next meeting of the International Congress of Orientalists, and inviting the Academy to send delegates, was referred to a committee, consisting of the President, the Vice-President of Class III., and the Corresponding Secretary.

James Ford Rhodes, of Boston, was elected a Resident Fellow in Class III., Section 3 (Political Economy and History).

On the motion of A. G. Webster, it was

Voted, That the date of reception be placed at the head of papers received for publication, instead of or in addition to the date of presentation, so that papers may be printed, if necessary, without waiting for presentation at a meeting.

Arthur G. Webster exhibited and described Maxwell's Dynamic Top.

The following papers were read by title: —

On Certain Derivatives of Symmetrical Trichlorbenzol. By C. Loring Jackson and F. H. Gazzolo.

On the Action of Sodic Ethylate on Tribromdinitrobenzol. By C. Loring Jackson and Waldemar Koch.

Trinitrophenylmalonic Ester, Second Paper. By C. Loring Jackson and J. I. Phinney.

A Revision of the Atomic Weight of Nickel, Second Paper. The Determination of the Nickel in Nickelous Bromide. By Theodore Wm. Richards and Allerton S. Cushman.

A Revision of the Atomic Weight of Cobalt, Second Paper. The Determination of the Cobalt in Cobaltous Bromide. By Theodore Wm. Richards and Gregory P. Baxter.

The Contact-potential between Metals and Fused Salts, and the Dissociation of Fused Salts. By Clarence McC. Gordon. Presented by Theodore Wm. Richards.

Some Electrochemical and Thermochemical Relations of Zinc and Cadmium Amalgams. By Theodore Wm. Richards and Gilbert N. Lewis.

On the Thermal Conductivity of Cast Iron. By Edwin H. Hall and C. H. Ayres.

On Fluctuations in the Composition of Natural Gas. By Francis C. Phillips. Presented by the C. M. Warren Committee.

Shoreline Topography. By F. P. Gulliver. Presented by W. M. Davis.

Nine hundred and Second Meeting.

NOVEMBER 23, 1898. — SPECIAL MEETING.

The Academy met at the house of the President, Cambridge.

The PRESIDENT in the chair.

The Chair announced the death of David Ames Wells, Associate Fellow in Class III., Section 3; and of Pierre Cécile Puvis de Chavannes, Foreign Honorary Member in Class III., Section 4.

A letter was read from the Corresponding Secretary of the Colonial Society of Massachusetts, thanking the Academy for past courtesies, and requesting the use of its hall for the five stated meetings of the Society during the ensuing year.

On the motion of the Recording Secretary, it was

Voted, To grant the request of the Colonial Society.

The following papers were presented by title: —

Japanese Collembola. By J. W. Folsom. Presented by S. H. Scudder.

The Use of the Transition Temperatures of Complex Systems as Fixed Points in Thermometry. By Theodore Wm. Richards and J. B. Churchill.

The following papers were read: —

On the Relationship of the Oceanic Currents and the Pelagic Fauna. By Alexander Agassiz.

Notes. (*a*) On Allen's Application of the Indicator Diagram to Rowing. (*b*) Progress in the Use of a Ring Pendulum for Gravity Determinations. By Thomas C. Mendenhall.

Nine Hundred and third Meeting.

DECEMBER 14, 1898.

The Academy met at the Jefferson Physical Laboratory, Cambridge.

VICE-PRESIDENT TROWBRIDGE in the chair.

John Trowbridge spoke on High Tension Electricity and exhibited a number of photographs which illustrated the disruptive effects of electrical discharges.

The Academy then visited the Laboratory rooms and witnessed several experiments, among which were the passage of electrical discharges over water in preference to a path through it, and other experiments illustrating the good conducting power of air under powerful electro-motive force. Electrical discharges six feet in length in ordinary air were shown, and it was made evident that in order to submit atmospheric air to a pressure of three million volts the apparatus would have to be raised to a considerable height above the earth, and be removed from all surrounding objects. The various investigations now being pursued in the Laboratory were explained, and the apparatus shown. Among these investigations were three which are being carried on under the aid of the Rumford Committee: one on Heat Conductivity, by B. O. Peirce and R. W. Willson; one also on Heat Conductivity, by Edwin H. Hall, who explained his apparatus; and one on the measurement of very short waves of light. In this latter subject Theodore Lyman and E. H. Colpitts have succeeded in obtaining the shortest wave lengths of metals hitherto measured.

Harold Edwards explained his investigation on measurements with an improved air thermometer. H. H. Brown exhibited his apparatus for the measurement of dielectrics, and a new method of measuring electric waves in air was described and exhibited.

John E. Wolff presented the following papers by title: —

A Comparative Study of Etch-figures: the Amphiboles and Pyroxenes. By R. A. Daly.

On the Optical Characters of the Vertical Zone of Amphiboles and Pyroxenes: and on a new Method of determining the Extinction-Angles of these Minerals by Means of Cleavage-Pieces. By R. A. Daly.

Nine hundred and fourth Meeting.

JANUARY 11, 1899. — STATED MEETING.

VICE-PRESIDENT HYATT in the chair.

The Corresponding Secretary read letters from the International Geographical Congress, announcing its seventh meet-

ing at Berlin on the 28th of September, 1899; from the Royal Academy of Sciences, Letters, and Arts in Modena, announcing the death of its President, Pietro Riccardi; and from James Ford Rhodes, accepting Fellowship in the Academy.

The Chair announced the death of John Cummings, of Woburn, Resident Fellow in Class III., Section 3.

Letters of resignation were received from Mellen Chamberlain, Charles James Sprague, and Warren Upham, Resident Fellows.

The following gentlemen were elected members of the Academy: —

Arthur Amos Noyes, of Boston, as Resident Fellow in Class I., Section 3 (Chemistry).

Henry Paul Talbot, of Newton, as Resident Fellow in Class I., Section 3.

Oliver Fairfield Wadsworth, of Boston, as Resident Fellow in Class II., Section 4 (Medicine and Surgery).

Charles Doolittle Walcott, of Washington, as Associate Fellow in Class II., Section 1 (Geology, Mineralogy, and Physics of the Globe), in place of the late James Hall.

Oliver Heaviside, of Newton Abbots, as Foreign Honorary Member in Class I., Section 2 (Physics).

John Fiske gave a talk on Eccentric Literature.

Remarks on this communication were made by E. H. Hall and T. C. Mendenhall.

Nine hundred and fifth Meeting.

FEBRUARY 8, 1899.

VICE-PRESIDENT HYATT in the chair.

John E. Wolff presented, by title, a paper by R. A. Daly, On a New Variety of Hornblende.

William E. Story gave a talk on some mathematical curiosities, exhibiting and explaining some things commonly called puzzles or tricks.

Nine hundred and sixth Meeting.

MARCH 8, 1899 — STATED MEETING.

VICE-PRESIDENT HYATT in the chair.

The Corresponding Secretary read a letter from the Imperial Mineralogical Society of St. Petersburg, announcing the death of Paul Ieremeiew.

The Chair appointed the following Councillors to serve as Nominating Committee: —

EDWIN H. HALL, of Class I.
BENJAMIN L. ROBINSON, of Class II.
JOHN E. HUDSON, of Class III.

The following papers were read: —

On Hardystonite, a new Calcium Zinc Silicate from Franklin Furnace, New Jersey. By John E. Wolff.

Investigations on Periodicity in the Weather. By H. Helm Clayton.

Remarks on these papers were made by Messrs. Story, Hall, and Webster.

The following papers were presented by title: —

Contributious from the Gray Herbarium of Harvard University, New Series. — No. XV. I. *Eleocharis ovata* and its American Allies. II. *Scirpus Eriophorum* and some related Forms. By M. L. Fernald. Presented by B. L. Robinson.

Contributions from the Gray Herbarium of Harvard University. — New Series, No. XVI. I. Revision of the Genera *Montanoa*, *Perymenium*, and *Zaluzania*. By B. L. Robinson and J. M. Greenman. II. Synopsis of the Genus *Verbesina*, with an analytical Key to the Species. By B. L. Robinson aud J. M. Greenman. III. Some new Species, extended Ranges, and newly noted Identities among the Mexican Phanerogams. By J. M. Greenman.

The Orthopteran Genus Schistocerca. By Samuel H. Scudder.

Nine hundred and seventh Meeting.

APRIL 12, 1899. — ADJOURNED STATED MEETING.

The Academy met at the Mineralogical Laboratory, University Museum, Cambridge.

The PRESIDENT in the chair.

The Chair announced the death of Othniel Charles Marsh, of New Haven, Associate Fellow in Class II., Section 3.

A letter was read from the Massachusetts Historical Society, thanking the Academy for the use of its hall for the meetings of the Society during the last two years.

The following papers were read: —

The Structure and Origin of Agates, illustrated by Specimens from the Bigelow Collection, and by the Projection on the Screen, by the Arc Light, of Sections in Polarized Light. By John E. Wolff.

A new Manganese Pyroxene from Franklin Furnace. By John E. Wolff.

Petrographical Notes on some Rocks from the Fiji Islands. By A. S. Eakle. Presented by J. E. Wolff.

A TABLE OF ATOMIC WEIGHTS

OF SEVENTY-FOUR ELEMENTS.

Compiled in April, 1899, from the most Recent Data.

BY THEODORE WILLIAM RICHARDS.

Name.	Symbol.	Atomic Weight.	Name.	Symbol.	Atomic Weight.
Aluminium . .	Al	27.1	Molybdenum .	Mo	96.0
Antimony . . .	Sb	120.0	Neodymium . .	Nd	143.6
Argon	A	39.9 ?	Nickel	Ni	58.70
Arsenic . . .	As	75.0	Niobium . . .	Nb = Cb	94.
Barium . . .	Ba	137.43	Nitrogen . . .	N	14.045
Beryllium . . .	Be = Gl	9.1	Osmium . . .	Os	190.8
Bismuth . . .	Bi	208.	Oxygen (standard)	O	16.000
Boron	B	10.95	Palladium . . .	Pd	106.5
Bromine . . .	Br	79.955	Phosphorus . .	P	31.0
Cadmium . . .	Cd	112.3	Platinum . . .	Pt	195.2
Cæsium . . .	Cs	132.9	Potassium . . .	K	39.140
Calcium . . .	Ca	40.1	Praseodymium .	Pr	140.5
Carbon	C	12.001	Rhodium . . .	Rh	103.0
Cerium . . .	Ce	140.	Rubidium . . .	Rb	85.44
Chlorine . . .	Cl	35.455	Ruthenium . .	Ru	101.7
Chromium . .	Cr	52.14	Samarium ? . .	Sm	150.
Cobalt	Co	59.00	Scandium	Sc	44. .
Columbium . .	Cb = Nb	94.	Selenium . . .	Se	79.2
Copper	Cu	63.60	Silicon	Si	28.4
"Didymium" .	Nd + Pr	142±	Silver	Ag	107.930
Erbium . . .	Er	166.	Sodium . . .	Na	23.050
Fluorine . . .	F	19.05	Strontium . . .	Sr	87.68
Gadolinium ? . .	Gd	156. ?	Sulphur . . .	S	32.065
Gallium . . .	Ga	70.0	Tantalum . . .	Ta	183.
Germanium . .	Ge	72.5	Tellurium . . .	Te	127.5 ?
Glucinum . . .	Gl = Be	9.1	Terbium ? . . .	Tb	160.
Gold	Au	197.3	Thallium . . .	Tl	204.15
Helium . . .	He	4.0 ?	Thorium . . .	Th	233.
Hydrogen . . .	H	1.0075	Thulium ? . . .	Tu	170. ?
Indium	In	114.	Tin	Sn	119.0
Iodine	I	126.85	Titanium . . .	Ti	48.17
Iridium . . .	Ir	193.0	Tungsten . . .	W	184.4
Iron	Fe	56.0	Uranium . . .	U	240.
Lanthanum . .	La	138.5	Vanadium . .	V	51.4
Lead	Pb	206.92	Ytterbium . .	Yb	173.
Lithium . . .	Li	7.03	Yttrium . . .	Yt	89 0
Magnesium . .	Mg	24.36	Zinc	Zn	65.40
Manganese . .	Mn	55.02	Zirconium . .	Zr	90.5
Mercury . . .	Hg	200.0			

(OVER)

NOTE.

Since the appearance of this table last year, the Committee of the German Chemical Society, Messrs. Landolt, Ostwald, and Seubert, have made their interesting report upon the subject, and have invited the chemists of the world to join them in deciding upon one standard to be used everywhere. The fulfilment of this very desirable end must necessarily be a matter of many months; hence the present table is republished this year in accordance with the original plan. It is to be distinctly understood that the republication is not in any way an attempt to compete with or to forestall the International Committee; it is merely an expression of opinion, which may be of temporary service. The fact that none of the other recent tables follow the accepted scientific usage concerning significant figures seems to afford an additional reason for reprinting this one.

The investigations of the past year have pointed to a change in four values given in the table of 1898. Calcium is made 40.1 instead of 40; for recent experiments (as yet unpublished) in this Laboratory indicate that last year's estimate was too low. Neo- and praseodymium were oddly transposed by their discoverer, and the more accurate values of Jones * and others are substituted. Lastly, Lenher's † careful investigation upon selenium seems to show that this element has a higher atomic weight than was formerly supposed to belong to it. For the present a compromise number, 79.2, is recorded above.

* Am. Chem. Journ., XX. 345 (1898).

† Journ. Am. Chem. Soc., XX. 555 (1898). Compare Clarke, Ibid., XXI. 200 (1899).

AMERICAN ACADEMY OF ARTS AND SCIENCES.

REPORT OF THE COUNCIL. — PRESENTED MAY 10, 1899.

BIOGRAPHICAL NOTICES.

REPORT OF THE COUNCIL.

SINCE the Annual Meeting of May 11, 1898, the Academy has lost by death nine members: — two Resident Fellows, John Cummings, Samuel Eliot; five Associate Fellows, Alvan Wentworth Chapman, Thomas McIntyre Cooley, James Hall, Othniel Charles Marsh, David Ames Wells; and two Foreign Honorary Members, Pierre Cécile Puvis de Chavannes and William Ewart Gladstone.

JUSTIN WINSOR.

THE career of JUSTIN WINSOR is remarkable both for what he accomplished, and for the way in which he accomplished it. There is a proverb that a man must make his mark before he is thirty, or he will never make it at all; but at that age Mr. Winsor had done little to attract public attention, or to give certain promise of great future usefulness and renown. The forces of his nature were still maturing, and it was not until the middle point of life had been passed that he gave proof of effective power. But the right opportunity had no sooner been presented than his intellectual resources and the vigor of his character were displayed with marvellous rapidity. Every decade revealed him as a leader in some new field of work, and in each he was a pioneer and a master.

He was born in Boston on January 2, 1831, and got his early education there. As a boy he was exceedingly fond of reading, and kept a diary in which he entered many statistics, scraps of history, and miscellaneous notes of all sorts. But he disliked school with its tasks, and did not enter Harvard College until he was more than eighteen years old, — rather an advanced age for a Boston boy in those days. His childhood, indeed, showed more than one point of contrast with his later life, for his silent, reserved, and somewhat unsociable tendencies were no less marked in his youth than his genial sympathy was in after times. The

qualities of his boyhood followed him to college and grew stronger there. He led the same half solitary life, devoting most of his time to reading by himself. He both read and wrote with the furious energy that always characterized him; yet at the time his efforts seemed fruitless, or at least misdirected. Before coming to college he had, it is true, written a History of the Town of Duxbury, which was published in his Freshman year; but although his ambition lay in literature, he met with no further success to encourage him. He took, for example, a great interest in the stage, and wrote dramas that were never acted. In 1850 he planned a life of Garrick, and for the next fifteen years he worked upon it, collecting a vast quantity of materials, but it never saw the light. He did not abandon, however, his love for historic research, and about this time he devised a systematic method of taking and arranging notes of his reading. This he continued to employ until near the end of his life, and by its aid he accumulated a reservoir of knowledge that was invaluable when an active career opened before him.

Although essentially a scholar, Mr. Winsor paid little attention to the curriculum of the College. At last it became irksome, positively repulsive to him, and, instead of graduating with his class in 1853, he left College, with the approval of President Sparks, at the beginning of his Senior year, and sailed for Europe. The next two years he spent in Paris and Heidelberg, reading, of course, assiduously, learning the languages, and preparing a book of translations and criticisms of German poetry. This again was never published as a whole, though many parts of it afterwards appeared in a fugitive form in several magazines.

In the autumn of 1854 he came home, and the next fourteen years were passed in study, and in writing frequent literary contributions for "The Crayon," "The Round Table," and other periodicals. A great deal of work was devoted also to his life of Garrick, which was brought nearly to completion; but as yet he had not found his true career. He had been industrious, but far less successful than his talents warranted, because his immense energy had not been turned in a direction where it could be effective. It is impossible to say how long it would have been before he discovered the right path, if an accident, or something very like an accident, had not revealed it to him.

In 1866 he was appointed a Trustee of the Boston Public Library, and the next year he made a report which attracted attention, and showed that he had grasped in a most extraordinary degree the problem of managing a great public library. In fact it outlined the changes that he was himself to carry out within the next few years. It so happened

that in 1868 the Superintendent died, and Mr. Winsor was asked to take the place, at first merely as a stop-gap, but soon as the permanent successor. His career had at last begun, and was destined to grow greater and greater till his death.

Mr. Winsor's opinions on libraries were at this time somewhat heretical. He believed that, to be useful, books ought to be read, and that the more they were read, the greater their usefulness became. He therefore strove not only to permit, but to encourage, in fact even to tempt, the public to use the library freely. With this object he lowered the age at which young people were allowed to take out books, and reduced the guaranties required of borrowers. He also gave up the customary habit of closing the library for a month every year for the purpose of cleaning and of inspecting the books, and he opened new avenues to the public by establishing branch libraries in various parts of the city. But this in itself was not enough for him, nor was it the most remarkable part of his innovations. To most people, a great library is nothing but a museum of incomprehensible things, — a labyrinth in which it is impossible to find one's way. Such people are perplexed and discouraged, feeling that the treasures of a library can be used only by the few learned persons who understand such subjects. Now Mr. Winsor set to work to make threads by means of which any one could find his way through the intricate maze of books, and he devised for that purpose a system of bulletins and annotated catalogues. Here his long habits of diligent reading and study and his prodigious memory helped him, for they had enabled him to acquire a bibliographic knowledge of marvellous range.

By methods of this kind, the annual circulation of books was increased seven-fold during Mr. Winsor's nine years' tenure of office. All these things have been developed since his time to such an extent that one finds it hard to realize how recent they are. The Boston Public Library does a vast deal more for the public to-day, and gives more assistance to readers in finding books by mean of bulletins and special catalogues than ever before, and all this is a development of the policy in which Mr. Winsor was a pioneer. The result has been to make reading more general throughout the community. It may almost be said to have made a thorough use of the library possible, for with the vast growth in the number of books the public would have found their use increasingly difficult without the system of dictionary catalogues that has come into existence.

Mr. Winsor had shown that he possessed both the capacity to conceive

what a great public library should be, and the executive ability to carry out his ideas. He was soon the foremost figure among the librarians of the United States, and in 1876 he was elected the first President of the newly formed American Library Association; but as yet he was not an historian. During his stay at the Public Library, his bibliographical work was connected rather with the institution than with the progress of American history. In 1877 he was transferred from the Boston Public Library to that of Harvard University. At the Harvard Library there still lingered traces of the old pagan superstition that the worst enemy of books was the general reader, who ought to be kept away from them by every competent librarian. But times were changing. The laboratory method of instruction had been winning one field of education after another, until it was rapidly becoming universal. Now Mr. Winsor, in harmony with the views that were rapidly gaining ground with the Professors, looked upon a library as being, for educational purposes, the laboratory of the literary and historical branches of study; and he gave his most cordial co-operation in putting the largest number of books at the disposal of the students with the greatest possible freedom.

But his work at Harvard was by no means confined to increasing the usefulness of the library. Without deserting his old line of activity, he opened a new one. He continued to write and edit bibliographies on various subjects, the most notable at this period being the "Readers' Handbook of the American Revolution," published in 1879. At the same time he made a new departure by undertaking to write history. Since he published his History of Duxbury as a lad, he had never lost his interest in the subject, and had never failed to devote much time to the study of it; but for more than thirty years he had not attempted to produce a history, and, when at last he took this work up again, it was in the new and peculiar form of co-operative authorship. In his earliest venture of the kind, the "Memorial History of Boston," published in 1880–81, he divided and assigned the various portions of the work among a number of writers, while he annotated the whole himself. The first experiment was soon followed by another, the "Narrative and Critical History of America," which was prepared upon the same plan, and published in parts from 1885 to 1889. These works have been criticised on the ground that they lack unity, and that the parts are of unequal value, — defects inseparable from the co-operative authorship. In fact, they are not histories so much as storehouses of information for historical students, and in this they fulfil the purpose for which they were designed. Mr. Winsor intended them to be a bibliographical and critical

record of all the sources of American history down to the middle of the present century, and he made himself beyond question the first authority on the subject in the United States. In fact, his position among historians was recognized by his election as President of the American Historical Association, just as his standing among librarians had been shown when he was chosen President of the American Library Association ten years before. In the seventies, he had surprised the world by proving himself a great librarian. In the eighties he had become a leading historian, and the first bibliographer of American history. The nineties were to show him in still another light.

Among the subjects in which he had always been interested, and which he treasured in his note books, was the study of maps, and this in turn was developed until he became the first cartographer of the United States. He applied his knowledge of maps to the subject of the discovery of America, and made himself so distinctly the authority on the geographical questions connected with the discovery and settlement of this country that the government naturally had recourse to him in the controversy about the Venezuela boundary. In a few years he produced four remarkable books, prepared, not as the earlier ones had been, on the co-operative plan, but written entirely by himself. The first of these four books, "The Voyages of Columbus," was published in 1891; the second, "Cartier to Frontenac," appeared in 1894; it was followed the next year by his work on the "Mississippi Basin"; and finally the last of the four on the "Western Movement," was in press at the time of his death, on October 22, 1897.

Industrious, painstaking, and energetic, Mr. Winsor accomplished an incredible amount of work in the last thirty years of his life; for it must be remembered that, although his work at the Boston Public Library was doubtless more arduous than that at Harvard, nevertheless the management of the Harvard Library is no sinecure, and he was managing this with the greatest diligence and efficiency during the very years when he was writing his great works on American history. But although his life became more and more full of labor as the years went by, he did not become absorbed in his work to the exclusion of other things, — he did not become so pressed that he could not spare time for social intercourse. On the contrary, his solitary habits wore away as his own life grew fuller, and with the increase in his activity and usefulness there developed his genial social side, his warm friendship for his fellows, and his kindliness for younger men.

A. Lawrence Lowell.

SAMUEL ELIOT.

Samuel Eliot, son of William Havard Eliot, whose wife was Margaret Bradford, was born in Boston on the 22d of December, 1821. In 1839 he was graduated from Harvard College. After a little experience of business life, he went abroad for a while. On his return he engaged in some schemes of charitable education, and in historical writing. In 1849 he published the first volume of his "History of Liberty"; the second followed in 1853; and in 1856 came his popular "History of the United States from 1492 to 1850." In this same year he became Professor of History at Trinity College, Hartford, Connecticut. Of this College he was President from 1860 to 1864. In 1872, having returned to Boston, where he lived thenceforth, he became master of the Girl's High School there. From 1878 to 1880 he was Superintendent of the Boston Public Schools; and afterwards, from 1885 to 1888, he was a member of the Boston School Committee.

His activity in charitable and other philanthropic work meanwhile was constant. To mention only a few of his services, he was for years a Trustee of the Massachusetts General Hospital, and during most of the time chairman of the board; for twenty six years he was President of the Perkins Institution and Massachusetts School for the Blind; and for twenty-one years President of the Massachusetts School for the Feeble Minded. He was President too of the Boston Episcopal Charitable Society. In more purely educational matters, and the like, he was equally active. For more than forty years he was a Trustee of St. Paul's School, at Concord, New Hampshire; for many years he was President of the Boston Athenæum; and from the foundation of the Boston Museum of Fine Arts until his death he was one of its Trustees. From 1866 to 1872 he was an Overseer of Harvard College. In brief, it is hard to name any position of educational or philanthropic trust in Boston which he was not called on to fill, and which he did not fill with unobtrusive distinction.

In 1863, while still President of Trinity College, he received from Columbia College the degree of LL. D.; and in 1880 he received the same honor from his own College, Harvard. In 1865 he became both a member of the Massachusetts Historical Society and a Fellow of the American Academy of Arts and Sciences. In 1853 he married Emily Marshall Otis, daughter of William Foster Otis, of Boston. Their two sons died, the younger in childhood, the elder at the age of twenty;

their daughter, Mrs. John Holmes Morison, survives. Dr. Eliot died at Beverly Farms, Massachusetts, on the 14th of September, 1898.

Among the traits which are passing from New England, and now rather enrich the memory of times gone by than give promise for the days to come, none was more marked than the personal distinction of our older gentry. The term may sound dissonant with the traditions of a democratic country. Yet whoever has known this region through the century which is closing must in candor admit that, for better or worse, we have had here social distinctions perhaps the more rigid because they were protected only by their own worth. The true worth of this New England gentry was nowhere more evident than in their deep sense of public duty. If they felt themselves born to the privilege of a certain social isolation, they felt, as every truly vital aristocracy must feel, that this privilege involved profound obligations. The older and officially recognized aristocracies of Europe find scope for their best powers in public careers, — military or political. In America, such careers, beset with far greater uncertainties than elsewhere, have proved less and less practicable for people of principle whose temper is not genuinely, unaffectedly democratic. Our first generation of independence, to be sure, found its highest ideal, military and civil alike, in Washington; our later century has found its chief civil hero in Lincoln, and its chief military hero in Grant, — admirable men, true worthies, but both alike sprung from the common people. In the generation which is passing, then, the old gentry of New England were mostly placed where they must either swerve from their traditions or do their public services elsewhere than in regular public life.

From this state of affairs has resulted a century of faithful activity in works which, while of public usefulness, are in many aspects private. Almost all of the serious literature of New England, like almost all of its riper scholarship, has been animated by its gentry. Almost all its great charities and public institutions have sprung from this class, and have been fostered by their care. To go no further than two instances familiar to all who know Boston, it is to our gentry, and almost to them alone, that we owe the Massachusetts General Hospital and the Boston Public Library, civic monuments which may serve as types of a hundred more, destined to survive any revolutions which may come, and so surviving to justify the lives and the privileges of the men to whom posterity shall owe them.

The older gentry of New England were probably at their best in a

generation which preceded Dr. Eliot's, — the generation preserved for us in the portraits of Gilbert Stuart. Their traditions, however, their principles, and to a great degree their manners, have here and there persisted; and in no familiar personality were they more typically present than in Dr. Eliot's own. His nature had a vitality, his temper a sunny freshness of feeling, — not inconsistent with occasional and sudden breezes, — which made him at seventy-five seem in many aspects almost a young man. And yet you could not see him or speak to him without the sense that here was one who could not be himself if for a moment he should strive to disguise that gracious personal distinction which marked the gentlemen of the elder time as distinct from the gentlemen of to-day and of the days to come. There was no lack of kindness in all this, no lack even of sympathetic affability, no lack of cordial human feeling such as heartily shares alike in joys and in sorrows. But there was a beautiful, impalpable something which forbade any thought or act of intrusive familiarity. His self-respect was so simple, so true, so worthy, that it could not fail instantly to command the respect of whoever had the privilege of meeting it.

For such a nature the most welcome vehicle of expression during Dr. Eliot's earlier years was probably literature, in its more scholarly aspect. Mr. Ticknor and Mr. Prescott were only a generation older than he; Mr. Motley and Mr. Parkman were his contemporaries. His earliest impulse, then, seems to have been towards that dignified and vigorous school of historical writing which is among the most precious possessions of New England. That kind of literature demands special gifts which he never quite revealed. His unfinished history shows neither such vivid power of concrete imagination as is essential to a notable historian, nor yet a vital command of style. In substance and in form alike it indicates little creative power. Whether he realized this, and so relinquished his pen, or whether the pressing call of other and more immediate duties diverted him from pure literature, it is hard to say. In either event, the experience might well have been disheartening. A man who has once felt the yearning to create works of art can seldom rest happy in any other effort. What is most characteristic of Dr. Eliot in all this, then, is that no one ever felt in him the least suggestion of disappointment or of discouragement. Among his many admirable traits, none was more salient than his constant, serene courage.

Disappointed or not, he found in the works which finally distracted him from literature opportunity for wider, more lasting usefulness than in mere letters he would ever have achieved. Very various these works

seem ; yet all agree in being at once private in form and public in scope. Though the superintendence of the Boston Public Schools may technically be held a public office, and surely is exposed to that ignoble kind of attack which to-day makes public office most repugnant to sensitive natures, it was in his hands as free from actual complication with politics and the like as was Trinity College, or the Athenæum, or St. Paul's School. His true career, then, through all the riper years of a manhood unbroken until the very end, was that of a faithful public servant, whose service was done in the unofficial retirement of privacy.

Professionally, so far as he can be held to have had a regular profession, he became a teacher, or perhaps one should rather say he devoted himself to education. As a Professor at Trinity College and for a while its President, as master of the Girls' High School in Boston and later as Superintendent of the Public Schools there, and for years as a Trustee of St. Paul's School at Concord, New Hampshire, he exerted a wide, varied, and constantly thoughtful influence on the education of New England. Precisely to define the nature of this influence and its result is needless. One thing about it seems certain. Wherever it was felt, and wherever it has persisted, it tended and it tends toward that sure righteousness of spirit which must come from ardently and constantly cherished ideals. In his public school work, to be sure, the condition of our society forbade him actively to assert the ideal which with him was doubtless the most profound. In his work at Trinity College, on the other hand, and in his constant watchfulness over St. Paul's School, he was able to care for this with all his heart and with all his power. For these, college and school alike, are not only institutions of learning but seminaries of religion, — and religion in that form which seemed to him most true, the gentle and flexible dogmatism of the Protestant Episcopal Church.

Not professedly religious, any more than was his work in the public schools, the other great range of his mature activity had in it something akin to consecration. In our time it has generally proved wisest to separate charity from dogma, — to serve the suffering and the wretched with no question as to anything but their sufferings and their needs. To charitable work, and especially such charitable work as should directly alleviate suffering, he gave himself with all his heart. The Massachusetts General Hospital, the Perkins Institution for the Blind, and many another admirable expression of the broadly humane benevolence which has marked our passing New England, owe as much to him as to any name in their history. In the coming time, to be sure, little distinct trace

of him may remain. This makes small difference; such work as his has the supreme grace of permeating that with which it deals. More and more, as one considers it, one feels that, for all the distinction of presence which in life made him always seem a personage, he labored in full humility of spirit, as a servant of the Master to whom his loyalty never wavered.

For, beyond doubt, the deepest trait of his true character was the simple fervor of his religious faith, a faith which sustained him in every trial, which inspired him in every duty. A single example of this will recur to whoever saw him in what must have been among the most trying moments of his later years. At a meeting in memory of an old friend, for whom he had personally cared, and whose character and life he had deeply respected, he was called on, amid the general eulogy, to pay his own tribute to the departed. He did not speak long; and he spoke kindly, gently, appreciatively. But you felt in his speech a touch of hesitation, a touch even of chill, which you did not quite understand. Then finally, — very simply, but very firmly, and with a rigidity of face which showed a rigid sense of duty impelling him, — he told us that he could not truthfully refrain from expressing his deep sorrow that our friend who was gone had not crowned a character which was almost complete by the final grace of Christianity. Written down, this act of his may seem bigoted, tactless, narrow. What made it so admirably memorable to those who witnessed it was the noble fearlessness of its conscientious sincerity, — a trait which freed it from all the invidiousness it might have had if the words had fallen from any other lips than his.

Such a memory of him as this might seem to imply that a dominant trait of his personal presence was austerity. Nothing could be further from the truth. It is doubtful, indeed, whether any of those who had the privilege to know him in the hearty intercourse of his private life, will remember anything of him sooner or more constantly than his simple, wholesome sense of humor. It was not that he uttered clever things, or told stories, or gave himself over to any conventional whimsicalities of thought or phrase. But in the unfailing oddities of daily life, in a thousand turns of fact or of speech which to most of us would seem commonplace, he found, with something like boyish zest, inexhaustible stimulus to such hearty, spontaneous laughter as speaks at once untrammelled power of enjoyment, unfailing sympathy with the little failings and vexations and absurdities of human beings, and all the while a singular purity of spirit.

Purity of spirit is what one finally feels to have been his rarest gift.

There were moments, no doubt, when this asserted itself in a somewhat rigid way. No man ever believed more firmly in the principles which his faith and his experience had combined to teach him; and, as the years passed, these principles had in them enough of the old school sometimes to formulate themselves in a manner which came very near to prejudice. Then appeared that firmness of feature from which every trace of laughter or mirth, of everything but deep, earnest conviction, had all faded. Then, instead of buoyant, cheery words came words of marked, cool, and sometimes sharp decision. And yet even in moments like these, when to those who did not wholly share his opinions and feelings his motives seemed least liberal, there was always an underlying, evident truth and simplicity of heart which brought, even with a sense of unmerited reproof, a feeling of tenderness for him. Like all of us, he was human, with foibles and with failings which he would have been the last to dissemble or to deny. He had the limits and the prejudices of his race and of his time; but more surely still he possessed the virtues of that vanishing old New England whose traditions he so loyally preserved to the end.

"Integer vitæ, scelerisque purus," wrote the Roman poet; and for centuries the words have been held to typify such a character as so lately has passed from among ourselves. And there is another saying, a sacred one which he would have cherished most, with little thought of how truly we who are left can repeat it of him: "Blessed are the pure in heart; for they shall see God."

BARRETT WENDELL.

JULES MARCOU.

JULES MARCOU, the subject of this notice, was born at Salins, France, April 20, 1824. He was educated at the College of Salins and the Lyceum of Besançon, and entered the College of St. Louis at Paris in October, 1842, but retired on account of ill health occasioned by too great application to mathematical studies in the spring of 1844, and returned to his native place. Previous to this three papers upon mathematical subjects had been accepted and published in the "Nouvelles Annales de Mathématiques," Terquem et Gérono, Paris, 1843–44.

By the advice of his family physician, Dr. Germain, he made long excursions on foot into the country around his native city, and in order to give objective interest to these walks collected and studied plants

with such energy that the knowledge obtained was of use to him in his subsequent work. Dr. Germain was in his leisure hours an enthusiastic collector of fossils, and possessed a considerable series of these which he had gathered himself. The interest excited in Marcou's mind by talks with Dr. Germain over his collection, and by tramps in company with him to deposits of organic remains in the strata of the Jura, gradually turned his attention from botany to the more exciting and absorbing pursuit of geology. The astonishingly active and original mind possessed by young Marcou, however, soon got beyond the stage of development reached by his teacher, and he speedily repaid his assistance by greatly increasing the value of his collections through his work in arranging, describing, and naming the specimens.

In consequence of his rising reputation Marcou was visited by Thurmann, then one of the most prominent of Swiss geologists, and also by Louis Agassiz. Both of these men, especially the latter, had great influence upon his subsequent career. It was largely owing to their encouragement that he offered for publication, in 1845, his first geological work, "Recherches Géologiques sur le Jura Salinois," which was published in "Mémoires de la Société d'Histoire Naturelle de Neuchâtel," of which Louis Agassiz was then editor, and subsequently appeared in fuller form in the "Mémoires de la Société Géologique de France," in 1846. The excellence of this work and his high recommendations made him the favored candidate for the chair of Professor of Mineralogy at the College of the Sorbonne in Paris in 1846. In 1847 he was intrusted with the important work of classifying the collections of fossil shells and corals in the Jardin des Plantes, and is said to have completed this task within a year, and so satisfactorily that he was offered by the great botanist Jussieu, then Director of the Jardin des Plantes, the position of Travelling Geologist, lately made vacant by the assassination of the former incumbent in Peru. This hazardous but much sought for post was exactly suited to his taste, and he accepted it joyfully, choosing for his field of exploration North America, principally on account of the presence of his friend Louis Agassiz in the United States.

His first expedition after his arrival in May, 1848, was with Agassiz upon the Lake Superior expedition in the same year; but he left the party at Keeweenaw Point to engage in the study of the copper bearing rocks of that region. His activity in travelling and collecting was at this time prodigious, and the mere list of the places visited and explored would be too long for so limited a notice as can be given here. He sent back to France large collections from many localities, ranging from

Richmond, Virginia, to Cape Breton and Quebec in Canada, and even as far west as Pittsburg and Cincinnati and Lake Superior.

In 1850 he married Miss Jane Belknap of Boston, and from that time he was actively seconded and assisted by this lady, whose devotion lightened the strains of his severest trials, including even that of his last sickness. Soon after his marriage he went back to France with his wife, but resigned before doing so the arduous post of Travelling Geologist, the duties of which had already begun to tell upon his not over strong constitution. He returned to America the following year, and immediately began the more minute study of the geology of New England, and also to write his "Geology of North America," the first work that attempted to assemble what was then known of the geology of this continent. This was published in 1853, and gave him naturally the best claim to be appointed geologist of one of the great expeditions then being organized by the United States for the survey of feasible routes for the projected railroads which were destined to unite the Atlantic and Pacific seaboards.

Professor Marcou accompanied the expedition under command of Lieutenant Whipple, which took the most southern route, departing from Napoleon on the Mississippi at the mouth of the Arkansas River in 1853. The main geological results of this expedition were the discovery of the wonderful structure of the great plateaus and the enormous deposits of secondary rocks in the Southwest, especially in the neighborhood of the Red River, and, although the age of these has since been settled differently from what was maintained by Professor Marcou, the importance of the facts and the credit due him as their first explorer have always been acknowledged. Unfortunately ill health obliged him to leave the United States for Europe in 1854, and he was forced to resign his position, and give up the hope of publishing his results in the official reports of the United States Survey.

The notes he had made were edited by W. P. Blake, and appeared in the Report published by the Senate, entitled "Explorations and Surveys of a Railroad Route from the Mississippi River to the Pacific Ocean," Vol. III., Washington, 1856.

Marcou was never satisfied with this necessarily meagre presentation of his views, and subsequently himself published a "Geology of North America, with two Reports on the Prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California, originally made for the United States Goverment," Zurich, 1858, with three maps and seven plates of fossils.

He was appointed Professor of Paleontology at the École Polytechnique at Zurich in 1856, and taught there for four years. The spirit of investigation and untiring devotion to science, however, was as great during this time as in previous years, and he continued publishing at intervals works of great importance upon the Jura, and began to write the manuscript of his "Geological Map of the World." The difficulties of this last work, including as it did extended correspondence with geologists in all parts of the world, and a vast amount of reading and compilation, were overcome only by untiring critical study and hard work; but the first and to the present time the only "Geological Map of the World" was constructed and finally published by him in 1862. This was the acme of his career, and probably no other geologist of his generation was so well qualified to accomplish such a general statement of what was then known of the geology of the world, and it must necessarily become the point of departure for all subsequent maps of this class.

Marcou resigned his professorship at Zurich, and returned to America in 1860 before this map was out of press, and there became involved in the great controversy with regard to Emmons's Taconic system of rocks. This, and the trips that he made into parts of New England in order to establish the credit of Emmons's discoveries of a primordial fauna, did not prevent him from making long journeys on his own account. We find him in the summer of 1863, during the dangerous times of the Civil War, exploring the country traversed by the Platte River and lying between the Kansas and Big Sioux. In 1875 he accompanied as geologist one of the expeditions under Lieut. Geo. M. Wheeler, which surveyed a portion of Southern California starting from Los Angeles, and his results were given in a "Report on the Geology of a Portion of Southern California" that appeared in the Report of Lieut. Wheeler's "Geographical Surveys West of the 100th Meridian" for 1876, included in the "Report of the Chief of Engineers," Part III., 1876. This seems to have been his last expedition to far western localities, and the remainder of his life was filled by one or two trips to and from Europe, and the writing of numerous papers mostly upon geology and of a controversial nature.

The biological side of his profession was regarded by Marcou as subservient to geology. In other words, he as a rule looked upon fossils mainly from the side of their importance in determining the age of strata, and yet to him belongs the credit of highly important results of a purely biological character. He was the first author to lead off in the effort to synchronize the different faunas of the Jura in Europe, and

Oppel, the most successful worker in this direction, always looked up to him as his teacher.

The eminent geologist of Vienna, Neumayr, and the author of this notice have always regarded themselves as following in his footsteps when endeavoring to map out the limits of the zones of life in geologic time, since Marcou in his "Roches des Jura" was the first author to distinctly define such areas of distribution. In that work he described tropical, temperate, and polar divisions in the Jura, and showed that the faunas of these circumterrestrial "bands" were distinguishable through the different characteristics of their faunas.

The writer's acquaintance with Prof. Marcou began during his first years of student life in Cambridge, and the kindly and courteous sympathy extended to him and to others was doubly grateful, since in those days personal interest and social intercourse between men in his position and students were exceptional.

Prof. Marcou's bibliography is extensive, one hundred and eighty-one titles being given in his manuscript list, extending from 1843 to the year of his death, 1898. This list shows that he completely gave up his early mathematical bent for geology, but he made one or two excursions into the domain of anthropology, and also into history, in his discussions of "the origin of the name America."

His most important independent work outside of geology was perhaps a book of 324 pages octavo, entitled, "De la Science en France," which appeared in 1869 in Paris, and excited great interest through its criticism of the official methods of conducting scientific institutions in that country. Another was a lively and interesting biography, the "Life, Letters, and Works of Louis Agassiz," in two volumes, 620 pages octavo, which appeared in this country in 1896.

Marcou was elected to membership in this Academy in November, 1861, and was also a member of the Geological Societies of London, Paris, Vienna, and Berlin. Numerous geographical and natural history societies had also honored him by election in France, Switzerland, Belgium, Russia, Germany, the United States, San Salvador, Mexico, Canada, Algeria, and Mozambique.

He was a lover of books, and his library contained a number of rare volumes, which he was always liberal in lending to investigators, and the writer frequently received assistance from him in this and in other ways that cannot be too gratefully acknowledged.

His acquaintance and correspondence with distinguished men in Europe and America were extensive and often intimate, and embraced many

illustrious persons outside of his own profession. His retentive memory was stored with reminiscences of personal intercourse with them, that at times made his conversation of surpassing interest.

His health during many years of his life was not good, and he was obliged to consider himself an invalid; but nevertheless his power of mental exertion remained apparently undiminished, and continued active until his last illness. He died at Cambridge, April 17, 1898, in consequence of an attack of pneumonia from which his enfeebled constitution was unable to rally. Had he lived three days more, he would have reached his seventy-third birthday.

ALPHEUS HYATT.

THEODORE LYMAN.

Resident Fellow Class II., Section 3, November, 1859. — Treasurer 1877–1883. — Secretary of Committee on the 100th Anniversary of the Founding of the Academy.

THEODORE LYMAN was born in Waltham, Mass., on the 23d of August, 1833, and died at Nahant, Mass., on the 9th of September, 1897. He was of the seventh generation in descent from Richard Lyman, the ancestor of the family, who came to this country in 1631 in the same ship with John Eliot, and the third successive bearer of the name Theodore Lyman.

The first Theodore Lyman, the grandfather of our late associate, came from old York, Maine, to Boston, and, as a successful merchant in this city, laid the foundation of the family fortunes.

His son, the second Theodore Lyman, studied in Europe in his early life, and, returning, served in the State Legislature from 1820 to 1825. He was Mayor of Boston in 1834–35, and while in this office defended William Lloyd Garrison from personal violence at the hands of a mob of respectable rioters to whom the fearless course of the abolitionist leader had given grave offence. Mayor Lyman secured the foundation of the Massachusetts State Reform School at Westboro, now appropriately known as the Lyman School, in grateful recognition of his endowment of the institution with a fund amounting to $72,500. He was a generous friend to the Massachusetts Historical Society, and to the Boston Farm School, an institution over which his son presided for several years. He was the author of works upon "The Political State of Italy" and "The Diplomacy of the United States," of small volumes entitled "Rambles in Italy" and "A few Weeks in Paris during the Residence of the Allied Sovereigns in that City," and of a Fourth of July Oration delivered in 1820.

The subject of the present sketch inherited his distinguished father's physique, as well as his intellectual traits and his strong sense of civic duties. He secured his early education from private instructors, spending two years in Europe from 1847 to 1849. While in Paris he suffered from a severe attack of typhoid fever, and also from weakness of the eyes. Returning home in 1849, he entered Harvard College in the Class of 1855, having among his classmates Alexander Agassiz and Phillips Brooks. During his college course we find evidences of his literary activity in the pages of the Harvard Magazine, a periodical founded by the classes of 1855 and 1856, but destined to be short-lived.

As if anticipating a career which was ten years later to engross his whole life and thought, his contributions were frequently upon military subjects, on which, as his classmate F. B. Sanborn says, "he joked with a substratum of excellent sense." His literary reputation as a student will, however, always rest securely on the song in which, as Chorister of the Hasty Pudding Club, he described the mystical origin of that ancient fraternity.

After graduation he studied for three years under the guidance of Prof. Louis Agassiz, and in 1858 received the degree of S. B. *summa cum laude*. The impressions produced upon him at this period of his life are recorded in an article entitled "Recollections of Agassiz," published in the Atlantic Monthly in 1874. The direction given to his studies by his great master was maintained during his whole life; and in recognition of the high value of his biological work his Alma Mater bestowed upon him in 1891 the honorary degree of LL. D.

Theodore Lyman's first public service was rendered in 1859–60 as a Trustee of the Reform School, which had been founded by the State at the instance and with the help of his father, for the instruction, employment, and reformation of juvenile offenders unfit to be at large, but not for boys who had become hardened by a prolonged vicious course, who were bad themselves and fitted to make others bad. By degrees however this purpose had been lost sight of, and vicious youths up to sixteen years of age had been committed to the School. The natural consequences ensued. $50,000 worth of property was destroyed by the burning of newly erected buildings by a boy who thus attempted to secure an alternate sentence, i. e. a short sentence to a penal institution, instead of being kept under guardianship at the School during minority. A return to the original plan of the founders of the School was secured through the strenuous exertions of Theodore Lyman, who, though the youngest member of the board, evidently prevailed in their counsels through the

same effective courage and energy which marked his later career, and did not quit the work until the Legislature had fixed the age limit at fourteen years, and had done away with the alternate sentence, placing all the boys in the School's custody during minority. It was not until 1884, when the Massachusetts Reformatory was established at Concord, that the age limit at Westboro was fixed at fifteen years, and provision was made for the transfer to Concord of boys who should prove to be unfit subjects for the Reform School, which was now by act of Legislature called "The Lyman School for Boys." A few years after its removal to a neighboring farm in the town of Westboro, Theodore Lyman came to the School for the dedication of the chapel, and, as he watched the boys at their work and play, he expressed his satisfaction at the success of the trustees in having at last made it very nearly the kind of school that his father had wished and hoped that it might become.

Theodore Lyman was married on November 28, 1856, to Elizabeth Russell, eldest daughter of George R. Russell, and a few years later went abroad for two years. It was during this period that his daughter Cora was born, in 1862. Returning home in 1863, he at once entered the military service of his country, then in the throes of civil war. He secured a commission as volunteer aid of the Governor of Massachusetts with the rank of Lieutenant Colonel, and was assigned to special duty at the headquarters of General Meade, with whom he had become very well acquainted before the war, and who was then in command of the Army of the Potomac. In this capacity he served till the end of the Civil War, taking part in the battles of the Wilderness, Spottsylvania Court House, and Cold Harbor, in the movements around Petersburg and in the final surrender at Appomattox Court House, where he was one of the few officers privileged to ride through the Confederate lines after the surrender. During all this period he showed an active and intelligent interest in his new work by making almost daily sketches showing the positions of the different corps of the Army of the Potomac. Mr. John C. Ropes, President of the Military Historical Society of Massachusetts, writes that he "was so much impressed with the value of these cartographic statements of the movements of the Army of the Potomac, from the autumn of 1863 down to and including the 9th of April, 1865, when Lee surrendered," that he had them all copied for the use of the Society. The same high authority in military matters speaks also of having seen extracts from a diary kept by Theodore Lyman during this period, "which are as humorous and as entertaining as any pictures of the camp

and march can possibly be." It is greatly to be hoped that this diary may in due time be edited and published, as it cannot fail to be a valuable contribution to our knowledge of the civil war. Few actors in this great drama had better opportunities of watching the succession of important historical events, or minds better qualified for observing, recording, and commenting upon them. Nor did his interest in military matters cease with the war, for, as a member of the Military Historical Society of Massachusetts he had ample opportunity to discuss with his companions in arms the great events in which they had all taken part. On June 11, 1877, he read a "Review of the Reports of Colonel Haven and General Weld on the conduct of General McClellan at Alexandria, in August, 1862, and on the case of Fitz John Porter."

Lyman maintained a close and unbroken friendship with General Meade until the death of the latter, in 1872. He then wrote an obituary notice of his old commander, which was published in Volume IX. of the Proceedings of this Academy.

During the twenty years following the close of the civil war Theodore Lyman's life was one of abounding activity, though before the end of this period the dread disease which was to make the closing years of his life a continual martyrdom had already marked him for its own.

To his Alma Mater he rendered important services as Overseer from 1868 to 1880, and from 1881 to 1888. Here his influence was always thrown in favor of liberty in the choice of studies and in attendance upon religious services. He was also one of the original Trustees and Treasurer of the Zoölogical Museum, a member and Secretary of the Museum Faculty, and Assistant in Zoölogy. The value of his services to the Museum in these various capacities was gratefully acknowledged by the Director, Alexander Agassiz, who, in his Annual Report for 1896–97 thus speaks of Lyman's scientific work: "His zoölogical work began with short papers on ornithological subjects; he subsequently became interested in corals, and finally devoted himself specially to Ophiurans. The first Illustrated Catalogue of the Museum was from his pen, and this important monograph on Ophiurans was followed by numerous papers on the same subject, treating of new species of the group. He wrote the Report on the Ophiurans of the 'Hassler' Expedition, of the 'Challenger,' and of the 'Blake,' which include by far the larger number of species of Ophiurans dredged by those deep-sea exploring expeditions."

On the establishment of the Commission of Inland Fisheries in 1866, Theodore Lyman became its first Chairman, and gave the State devoted

service for seventeen years without compensation. The story of his disinterested labor in this field is told in the Commissioners' Annual Reports, many of which are from his own pen, and are characterized by a brightness of style which pleasantly relieves the gravity of an official document.

In 1884, as President of the American Fish Cultural Association, at the thirteenth annual meeting held in Washington on May 13, he delivered an address which is printed in the 19th Annual Report of the Commissioners of Inland Fisheries of Massachusetts. Here he sketches in the most charming manner the history of the fish industries of New England from the time when the inhabitants were wont to "dunge their grounds with codd." He shows that fifty years after the settlement of the country a diminution in the number of fish in the New England rivers had already been noted, and describes the various laws enacted for their protection, culminating in 1864–65 in modern fish culture under the auspices of several State governments, and finally in the appointment in 1871 of the United States Fish Commission under the leadership of Professor Spencer F. Baird.

The various fishery commissions of the country have, to use Theodore Lyman's own words, "accumulated a vast amount of accurate information concerning the numbers and variety of our fishes, their food, manner of breeding, condition of life, migration, and stages of growth." Pisciculture has become a State and national industry, while many private fish preserves have been established in various parts of the country. Several species of Salmonidæ are raised regularly for the market, and it is highly probable that nearly all the shad now taken in our Atlantic streams have originated in State or national hatching establishments. These results, though important, merely serve to indicate what great additions to the wealth of the country may be effected when water culture is "practised as universally and methodically as is agriculture." When Americans shall have learned to cultivate the water thus methodically, and shall desire to honor the men who in their day and generation have labored to re-establish the fisheries of the country, no name will stand higher on the list than that of Theodore Lyman.

In politics Theodore Lyman was distinguished for independence and an earnest advocacy of civil service reform, a cause which, as founder and Vice President of the Massachusetts Reform Club, he sought in every way to promote. He was elected to Congress from the Ninth District in 1882, and, though handicapped by increasing infirmities, nobly represented the State "as long as patriotism was more prized in his district

than partisanship."* His independent course in politics was naturally distasteful to many political leaders, and, at the time of the "Mugwump" defection from the Republican party, called down upon him some severe animadversions from Senator Hoar. On this occasion he, with exquisite humor and with generous consideration for his antagonist, compared himself to a fellow who boasted to his neighbors that he had "just been cuffed by the King."

In November, 1869, he was elected a Resident Member of the Massachusetts Historical Society, and in December, 1880, he read before the Society a memoir of his father-in-law, George R. Russell.

He was also a Trustee of the Peabody Educational Fund.

Theodore Lyman did so much work of a high order in so many different directions that it is difficult to decide in what calling he was most fitted to excel. That he possessed a decided aptitude for the duties of a soldier is the opinion of those best qualified to judge, and it is not at all improbable that when, in the fulness of time, his diary shall be given to the public, his place among the military writers of the world will be definitely assured.

His high character and his firm conviction that "public office is a public trust" well fitted him for the career of a statesman, and there is little doubt that he would have distinguished himself in public life had circumstances favored the adoption of such a career.

His scientific papers are examples of conscientious observation, and are valuable contributions to the field of knowledge in which he labored.

Perhaps the trait of character which most impressed itself upon all who came in contact with Theodore Lyman was the cheerfulness and gayety of his disposition. This gayety was far removed from frivolity, and was compatible with a stern expression of indignation whenever circumstances called it forth. In this spirit were compiled the "Papers relating to the Garrison Mob,"† in which the son indignantly repels the criticisms of Wendell Phillips upon the conduct of the father on that memorable occasion.

Another remarkable trait in Theodore Lyman's character was the alertness of his mind, which, combined with the gayety of his nature, made his companionship both socially and intellectually so charming. Even in his serious writings, e. g. in his Reports as Fish Commissioner, his exuberant vitality and his cheerful humor found expression, but it was, of

* "H. L.," Transcript, Sept. 15, 1897.
† Cambridge, Welch, Bigelow, & Co., 1870.

course, in his personal intercourse with his companions that this charm was most distinctly felt. It was this which led to his being for many years, by common consent, chairman of his Class dinners, as the Class Secretary E. H. Abbot tells us in a most appropriate and affectionate notice of him prepared for distribution to the members of the Class of 1855.

The members of the Thursday Evening Club, over which he presided for many years, will long remember the way in which the meetings were enlivened by his ready wit, and the happy manner in which he introduced the successive speakers.

Upon this life, so filled with everything that could make life enjoyable, early fell the shadow of a mortal disease, so gradual in its approach that few of his friends were aware that the first warning came sixteen years before his death. During this period he was, in the words of his friend and classmate, E. H. Abbot, "day by day parting with the power to act, until at last he was forced to stand still and watch the stream of life flow by; a soul imprisoned in a body which was gradually losing all power of movement, and which at last became absolutely helpless and dependent for every service upon external aid. To him of all men these years of prolonged and growing uselessness must have seemed a living death. And yet they who know most about him know that those years were really the noblest of his life. His brave spirit in this growing isolation, which at last withdrew him from the sight of almost all except his own family, surmounted all barriers. He never permitted himself to lose his active interest in the events of other lives. He cheered on the doers of good all over the world by messages which came from his chamber with all their old-time gayety and brightness. When his hand could no longer hold the pen, he spoke through his tender amanuensis words full of the same high courage and cheerful humor which had been his charm in earlier life."

In concluding this brief notice of Theodore Lyman, it may perhaps be permitted to supplement the above tender and truthful description of his last years with a few words employed by the writer of this sketch to introduce a resolution of the Thursday Evening Club replying to an affectionate message from its former President on the fiftieth anniversary of its foundation: —

"I remember, Mr. President, when a young man, looking around among the men of my generation and considering whose lot in life seemed to me, on the whole, the most enviable. I came to the conclusion that Theodore Lyman was, of all my acquaintances, the man for whom the future seemed to hold out the brightest promise.

"In vigorous health, with a personality physical, mental, and moral which endeared him to all who came in contact with him, happily married, with instincts and powers which led him to the highest callings, to the service of his country in the field and in legislative halls, with tastes for the study of the natural sciences and abundant means to gratify them, there seemed to be nothing lacking to make his life an ideally happy one.

"Then, when the shadow of a slow insidious disease fell upon him, it seemed for a time as if his life were but to afford another illustration of the old Greek saying that no man is to be judged happy before his death. But when I saw how bravely he met the advances of his enemy, and with what courageous cheerfulness he interested himself in the pursuits of his friends and in the active life around him in which he could no longer share, I could not help feeling that a happiness was reserved for him higher than any of which the Greek philosopher had dreamed, or I, as a young man, had formed a conception, — the happiness of knowing that by the force of his example he had helped to raise those who came under its influence to a higher and nobler life."

HENRY P. BOWDITCH.

Other notices are postponed.

Three Resident Fellows have resigned, and the Academy has received an accession of seven Resident Fellows, one Associate Fellow, and two Foreign Honorary Members.

The roll of the Academy, corrected to date, includes the names of 193 Resident Fellows, 92 Associate Fellows, and 66 Foreign Honorary Members.

BOSTON, May 10, 1899.

LIST

OF THE

FELLOWS AND FOREIGN HONORARY MEMBERS.

(Corrected to June 1, 1899.)

RESIDENT FELLOWS. — 195.

(Number limited to two hundred.)

CLASS I. — *Mathematical and Physical Sciences.* — 78.

SECTION I. — 18.

Mathematics and Astronomy.

Solon I. Bailey,	Cambridge.
William E. Byerly,	Cambridge.
Seth C. Chandler,	Cambridge.
J. Rayner Edmands,	Cambridge.
Gustavus Hay,	Boston.
Henry Mitchell,	Nantucket.
James Mills Peirce,	Cambridge.
Edward C. Pickering,	Cambridge.
William H. Pickering,	Cambridge.
John Ritchie, Jr.,	Boston.
John D. Runkle,	Brookline.
T. H. Safford,	Williamstown.
Edwin F. Sawyer,	Brighton.
Arthur Searle,	Cambridge.
William E. Story,	Worcester.
Henry Taber,	Worcester.
O. C. Wendell,	Cambridge.
P. S. Yendell,	Dorchester.

SECTION II. — 23.

Physics.

A. Graham Bell,	Washington.
Clarence J. Blake,	Boston.
Francis Blake,	Weston.
John H. Blake,	Boston.
Charles R. Cross,	Brookline.
Amos E. Dolbear,	Somerville.
H. M. Goodwin,	Boston.
Edwin H. Hall,	Cambridge.
Hammond V. Hayes,	Cambridge.
Silas W. Holman,	Brookline.
William L. Hooper,	Somerville.
William W. Jacques,	Newton.
Frank A. Laws,	Boston.
Henry Lefavour,	Williamstown.
T. C. Mendenhall,	Worcester.
Benjamin O. Peirce,	Cambridge.
A. Lawrence Rotch,	Boston.
Wallace C. Sabine,	Cambridge.
John S. Stone,	Boston.
Elihu Thomson,	Swampscott.
John Trowbridge,	Cambridge.
A. G. Webster,	Worcester.
Robert W. Willson,	Cambridge.

SECTION III. — 23.

Chemistry.

Samuel Cabot,	Boston.
Arthur M. Comey,	Cambridge.
Thos. M. Drown,	So. Bethlehem, Pa.
Charles W. Eliot,	Cambridge.
Thomas Gaffield,	Boston.
Henry B. Hill,	Cambridge.
Charles L. Jackson,	Cambridge.

Walter L. Jennings,	Worcester.
Leonard P. Kinnicutt,	Worcester.
Charles F. Mabery,	Cleveland, O.
Arthur Michael,	Boston.
George D. Moore,	Worcester.
Charles E. Munroe,	Washington.
John U. Nef,	Chicago.
Arthur A. Noyes,	Boston.
Robert H. Richards,	Boston.
Theodore W. Richards,	Cambridge.
Charles R. Sanger,	Cambridge.
Stephen P. Sharples,	Cambridge.
Francis H. Storer,	Boston.
Henry P. Talbot,	Newton.
Charles H. Wing,	Ledger, N. C.
Edward S. Wood,	Boston.

Section IV. — 14.

Technology and Engineering.

Eliot C. Clarke,	Boston.
Ira N. Hollis,	Cambridge.
Gaetano Lanza,	Boston.
E. D. Leavitt,	Cambridgeport.
William R. Livermore,	Boston.
Hiram F. Mills,	Lowell.
Cecil H. Peabody,	Boston.
Alfred P. Rockwell,	Manchester.
Andrew H. Russell,	St. Paul, Minn.
Peter Schwamb,	Arlington.
Charles S. Storrow,	Boston.
George F. Swain,	Boston.
William Watson,	Boston.
Morrill Wyman,	Cambridge.

Class II. — *Natural and Physiological Sciences.* — 61.

Section I. — 12.

Geology, Mineralogy, and Physics of the Globe.

H. H. Clayton,	Milton.
Algernon Coolidge,	Boston.
William O. Crosby,	Boston.
William M. Davis,	Cambridge.
Benj. K. Emerson,	Amherst.
O. W. Huntington,	Newport, R. I.
Robert T. Jackson,	Boston.
William H. Niles,	Cambridge.
John E. Pillsbury,	Boston.
Nathaniel S. Shaler,	Cambridge.
Robert DeC. Ward,	Boston.
John E. Wolff,	Cambridge.

Section II. — 10.

Botany.

Geo. E. Davenport,	Medford.
William G. Farlow,	Cambridge.
Charles E. Faxon,	Boston.
George L. Goodale,	Cambridge.
H. H. Hunnewell,	Wellesley.
John G. Jack,	Boston.
B. L. Robinson,	Cambridge.
Charles S. Sargent,	Brookline.
Arthur B. Seymour,	Cambridge.
Roland Thaxter,	Cambridge.

Section III. — 24.

Zoölogy and Physiology.

Alexander Agassiz,	Cambridge.
Robert Amory,	Boston.
James M. Barnard,	Milton.
Henry P. Bowditch,	Boston.
William Brewster,	Cambridge.
Louis Cabot,	Brookline.
Samuel F. Clarke,	Williamstown
W. T. Councilman,	Boston.
Charles B. Davenport,	Cambridge.
Harold C. Ernst,	Boston.
J. Walter Fewkes,	Washington, D.C.
Edward G. Gardiner,	Boston.
Samuel Henshaw,	Cambridge.
Alpheus Hyatt,	Cambridge.
John S. Kingsley,	Somerville.
Edward L. Mark,	Cambridge.
Charles S. Minot,	Boston.
Edward S. Morse,	Salem.

George H. Parker,	Cambridge.
James J. Putnam,	Boston.
Samuel H. Scudder,	Cambridge.
William T. Sedgwick,	Boston.
James C. White,	Boston.
William M. Woodworth,	Cambridge.

SECTION IV. — 15.

Medicine and Surgery.

Samuel L. Abbot,	Boston.
Edward H. Bradford,	Boston.
Arthur T. Cabot,	Boston.
David W. Cheever,	Boston.
Frank W. Draper,	Boston.
Thomas Dwight,	Boston.
Reginald H. Fitz,	Boston.
Charles F. Folsom,	Boston.
Frederick I. Knight,	Boston.
Samuel J. Mixter,	Boston.
W. L. Richardson,	Boston.
Theobald Smith,	Boston.
O. F. Wadsworth,	Boston.
Henry P. Walcott,	Cambridge.
John C. Warren,	Boston.

CLASS III. — *Moral and Political Sciences.* — 56.

SECTION I. — 10.

Philosophy and Jurisprudence.

James B. Ames,	Cambridge.
Charles C. Everett,	Cambridge.
Horace Gray,	Boston.
John C. Gray,	Boston.
G. Stanley Hall,	Worcester.
• Nathaniel Holmes,	Cambridge.
John E. Hudson,	Boston.
Francis C. Lowell,	Boston.
Josiah Royce,	Cambridge.
James B. Thayer,	Cambridge.

SECTION II. — 21.

Philology and Archæology.

William S. Appleton,	Boston.
Charles P. Bowditch,	Boston.
Lucien Carr,	Cambridge.
Franklin Carter,	Williamstown.
Joseph T. Clarke,	Boston.
Henry G. Denny,	Boston.
Epes S. Dixwell,	Cambridge.
William Everett,	Quincy.
William W. Goodwin,	Cambridge.
Henry W. Haynes,	Boston.
Charles R. Lanman,	Cambridge.
David G. Lyon,	Cambridge.
Bennett H. Nash,	Boston.
Frederick W. Putnam,	Cambridge.
Edward Robinson,	Boston.
F. B. Stephenson,	Boston.
Joseph H. Thayer,	Cambridge.
Crawford H. Toy,	Cambridge.
John W. White,	Cambridge.
John H. Wright,	Cambridge.
Edward J. Young,	Waltham.

SECTION III. — 13.

Political Economy and History.

Charles F. Adams,	Lincoln.
Edward Atkinson,	Boston.
Andrew M. Davis,	Cambridge.
Charles F. Dunbar,	Cambridge.
John Fiske,	Cambridge.
A. C. Goodell,	Salem.
Henry C. Lodge,	Nahant.
A. Lawrence Lowell,	Boston.
Augustus Lowell,	Boston.
James F. Rhodes,	Boston.
John C. Ropes,	Boston.
Denman W. Ross,	Cambridge.
Charles C. Smith,	Boston.

SECTION IV.—12.

Literature and the Fine Arts.

Francis Bartlett,	Boston.
John Bartlett,	Cambridge.
George S. Boutwell,	Groton.
J. Elliot Cabot,	Brookline.
T. W. Higginson,	Cambridge.
George L. Kittredge,	Cambridge.
S. R. Koehler,	Boston.
Charles G. Loring,	Boston.
Percival Lowell,	Brookline.
Charles Eliot Norton,	Cambridge.
Horace E. Scudder,	Cambridge.
Barrett Wendell,	Boston.

ASSOCIATE FELLOWS. — 91.

(Number limited to one hundred. Elected as vacancies occur.)

CLASS I. — *Mathematical and Physical Sciences.* — 34.

SECTION I. — 14.

Mathematics and Astronomy.

Edward E. Barnard,	Chicago.
S. W. Burnham,	Chicago.
George Davidson,	San Francisco.
Fabian Franklin,	Baltimore.
Asaph Hall,	Cambridge.
George W. Hill,	Washington.
E. S. Holden,	Washington.
James E. Keeler,	Mt. Hamilton, Cal.
Emory McClintock,	New York.
Simon Newcomb,	Washington.
Charles L. Poor,	Baltimore.
George M. Searle,	Washington.
J. N. Stockwell,	Cleveland, O.
Chas. A. Young,	Princeton, N. J.

SECTION II. — 6.

Physics.

Carl Barus,	Providence, R.I.
J. Willard Gibbs,	New Haven.
S. P. Langley,	Washington.
A. A. Michelson,	Chicago.
Ogden N. Rood,	New York.
H. A. Rowland,	Baltimore.

SECTION III. — 7.

Chemistry.

Wolcott Gibbs,	Newport, R.I.
Frank A. Gooch,	New Haven.
S. W. Johnson,	New Haven.
J. W. Mallet,	Charlottesville, Va.
E. W. Morley,	Cleveland, O.
J. M. Ordway,	New Orleans.
Ira Remsen,	Baltimore.

SECTION IV. — 7.

Technology and Engineering.

Henry L. Abbot,	New York.
Cyrus B. Comstock,	Washington.
W. P. Craighill,	Washington.
F. R. Hutton,	New York.
George S. Morison,	Chicago.
William Sellers,	Philadelphia.
Robt. S. Woodward,	New York.

CLASS II. — *Natural and Physiological Sciences.* — 31.

SECTION I. — 15.

Geology, Mineralogy, and Physics of the Globe.

Cleveland Abbe,	Washington.
George J. Brush,	New Haven.
Edward S. Dana,	New Haven.
Walter G. Davis,	Cordova, Arg.
Sir J. W. Dawson,	Montreal.
G. K. Gilbert,	Washington.
Clarence King,	New York.
Joseph LeConte,	Berkeley, Cal.
J. Peter Lesley,	Milton, Mass.
S. L. Penfield,	New Haven.
J. W. Powell,	Washington.
R. Pumpelly,	Newport, R.I.
A. R. C. Selwyn,	Ottawa.
G. C. Swallow,	Columbia, Mo.
Charles D. Walcott,	Washington.

Section II. — 4.

Botany.

D. H. Campbell,	Palo Alto, Cal.
J. M. Coulter,	Chicago.
W. Trelease,	St. Louis.
John D. Smith,	Baltimore.

Section III. — 5.

Zoölogy and Physiology.

Joel A. Allen,	New York.
W. K. Brooks,	Baltimore.
S. Weir Mitchell,	Philadelphia.
A. S. Packard,	Providence, R.I.
A. E. Verrill,	New Haven.

Section IV. — 7.

Medicine and Surgery.

John S. Billings,	New York.
Jacob M. Da Costa,	Philadelphia.
W. A. Hammond,	New York.
William Osler,	Baltimore.
Alfred Stillé,	Philadelphia.
Wm. H. Welch,	Baltimore.
H. C. Wood,	Philadelphia.

Class III. — *Moral and Political Sciences.* — 26.

Section I. — 5.

Philosophy and Jurisprudence.

James C. Carter,	New York.
D. R. Goodwin,	Philadelphia.
Charles S. Peirce,	New York.
T. R. Pynchon,	Hartford, Conn.
Jeremiah Smith,	Cambridge.

Section II. — 7.

Philology and Archæology.

A. N. Arnold,	Pawtuxet, R.I.
Timothy Dwight,	New Haven.
B. L. Gildersleeve,	Baltimore.
D. C. Gilman,	Baltimore.
T. R. Lounsbury,	New Haven.
E. E. Salisbury,	New Haven.
A. D. White,	Ithaca, N.Y.

Section III. — 6.

Political Economy and History.

Henry Adams,	Washington.
G. P. Fisher,	New Haven.
H. E. von Holst,	Chicago.
Henry C. Lea,	Philadelphia.
Edward J. Phelps,	Burlington, Vt.
W. G. Sumner,	New Haven.

Section IV. — 8.

Literature and the Fine Arts.

James B. Angell,	Ann Arbor, Mich.
L. P. di Cesnola,	New York.
F. E. Church,	New York.
H. H. Furness,	Philadelphia.
R. S. Greenough,	Florence.
Augustus St. Gaudens,	New York.
E. C. Stedman,	Bronxville, N.Y.
W. R. Ware,	New York.

FOREIGN HONORARY MEMBERS.—67.

(Number limited to seventy-five. Elected as vacancies occur.)

Class I.—*Mathematical and Physical Sciences.*—21.

Section I.—7.

Mathematics and Astronomy.

Arthur Auwers,	Berlin.
George H. Darwin,	Cambridge.
H. A. E. A. Faye,	Paris.
Charles Hermite,	Paris.
William Huggins,	London.
Otto Struve,	Karlsruhe.
H. C. Vogel,	Potsdam.

Section II.—5.

Physics.

Ludwig Boltzmann,	Vienna.
A. Cornu,	Paris.
Oliver Heaviside,	Newton Abbots.
Lord Rayleigh,	Witham.
Sir G. G. Stokes, Bart.,	Cambridge.

Section III.—7.

Chemistry.

Adolf Baeyer,	Munich.
Marcellin Berthelot,	Paris.
Robert Bunsen,	Heidelberg.
J. H. van't Hoff,	Berlin.
D. Mendeleeff,	St. Petersburg.
Sir H. E. Roscoe,	London.
Julius Thomsen,	Copenhagen.

Section IV.—2.

Technology and Engineering.

Lord Kelvin,	Glasgow.
Maurice Lévy,	Paris.

Class II.—*Natural and Physiological Sciences.*—23.

Section I.—5.

Geology, Mineralogy, and Physics of the Globe.

Albert Heim,	Zurich.
A. E. Nordenskiöld,	Stockholm.
C. F. Rammelsberg,	Berlin.
Henry C. Sorby,	Sheffield.
Heinrich Wild,	Zurich.

Section II.—6.

Botany.

J. G. Agardh,	Lund.
E. Bornet,	Paris.
Sir Joseph D. Hooker,	Sunningdale.
W. Pfeffer,	Leipsic.
Solms-Laubach,	Strassburg.
Eduard Strasburger,	Bonn.

Section III. — 7.

Zoölogy and Physiology.

Michael Foster,	Cambridge.
Carl Gegenbauer,	Heidelberg.
Ludimar Hermann,	Königsberg.
Albrecht Kölliker,	Würzburg.
A. Kovalevsky,	St. Petersburg.
Lacaze-Duthiers,	Paris.
Elias Metschnikoff,	Paris.

Section IV. — 5.

Medicine and Surgery.

W. Kühne,	Heidelberg.
Lord Lister,	London.
Sir James Paget, Bart.,	London.
F. v. Recklinghausen,	Strassburg.
Rudolph Virchow,	Berlin.

Class III. — *Moral and Political Sciences.* — 23.

Section I. — 6.

Philosophy and Jurisprudence.

Heinrich Brunner,	Berlin.
F. W. Maitland,	Cambridge.
James Martineau,	London.
Sir Frederick Pollock,	Oxford.
Baron Russell of Killowen,	Tadworth.
Henry Sidgwick,	Cambridge.

Section II. — 7.

Philology and Archæology.

Ingram Bywater,	Oxford.
W. Dörpfeld,	Athens.
Sir John Evans,	Hemel Hempstead.
J. W. A. Kirchhoff,	Berlin.
G. C. C. Maspero,	Paris.
Max Müller,	Oxford.
Karl Weinhold,	Berlin.

Section III. — 5.

Political Economy and History.

Duc de Broglie,	Paris.
James Bryce,	Oxford.
Hermann Grimm,	Berlin.
Theodor Mommsen,	Berlin.
William Stubbs,	Oxford.

Section IV. — 5.

Literature and the Fine Arts.

Georg Brandes,	Copenhagen.
F. Brunetière,	Paris.
Jean Léon Gérôme,	Paris.
John Ruskin,	Coniston.
Leslie Stephen,	London.

STATUTES AND STANDING VOTES.

STATUTES.

Adopted May 30, 1854 : *amended September* 8, 1857, *November* 12, 1862, *May* 24, 1864, *November* 9, 1870, *May* 27, 1873, *January* 26, 1876, *June* 16, 1886, *October* 8, 1890, *January* 11 *and May* 10, 1893, *April* 11, *May* 9, *and October* 10, 1894, *and March* 13, *April* 10, *and May* 8, 1895.

CHAPTER I.

OF FELLOWS AND FOREIGN HONORARY MEMBERS.

1. The Academy consists of *Fellows* and *Foreign Honorary Members.* They are arranged in three Classes, according to the Arts and Sciences in which they are severally proficient, viz.: Class I. The Mathematical and Physical Sciences; — Class II. The Natural and Physiological Sciences; — Class III. The Moral and Political Sciences. Each Class is divided into four Sections, viz.: Class I., Section 1. Mathematics and Astronomy; — Section 2. Physics; — Section 3. Chemistry; — Section 4. Technology and Engineering. Class II., Section 1. Geology, Mineralogy, and Physics of the Globe; — Section 2. Botany; — Section 3. Zoölogy and Physiology; — Section 4. Medicine and Surgery. Class III., Section 1. Philosophy and Jurisprudence; — Section 2. Philology and Archæology; — Section 3. Political Economy and History; — Section 4. Literature and the Fine Arts.

2. Fellows, resident in the State of Massachusetts, only, may vote at the meetings of the Academy.* Each Resident Fellow shall pay an admission fee of ten dollars and such annual assessment, not exceeding ten dollars, as shall be voted by the Academy at each Annual Meeting.

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* The number of Resident Fellows is limited by the Charter to 200.

3. Fellows residing out of the State of Massachusetts shall be known and distinguished as Associate Fellows. They shall not be liable to the payment of any fees or annual dues, but on removing within the State shall be admitted to the privileges,* and be subject to the obligations, of Resident Fellows. The number of Associate Fellows shall not exceed *one hundred*, of whom there shall not be more than *forty* in either of the three Classes of the Academy.

4. The number of Foreign Honorary Members shall not exceed *seventy-five;* and they shall be chosen from among persons most eminent in foreign countries for their discoveries and attainments in either of the three departments of knowledge above enumerated. And there shall not be more than *thirty* Foreign Members in either of these departments.

CHAPTER II.

Of Officers.

1. There shall be a President, three Vice-Presidents, one for each Class, a Corresponding Secretary, a Recording Secretary, a Treasurer, and a Librarian, which officers shall be annually elected, by ballot, at the Annual Meeting, on the second Wednesday in May.

2. At the same time, and in the same manner, nine Councillors shall be elected, three from each Class of the Academy, but the same Fellows shall not be eligible on more than three successive years. These nine Councillors, with the President, the three Vice-Presidents, the two Secretaries, the Treasurer, and the Librarian, shall constitute the Council. It shall be the duty of this Council to exercise a discreet supervision over all nominations and elections. With the consent of the Fellow interested, they shall have power to make transfers between the several Sections of the same Class, reporting their action to the Academy.

3. If any office shall become vacant during the year, the vacancy shall be filled by a new election, and at the next stated meeting, or at a meeting called for this purpose.

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* Associate Fellows may attend, but cannot vote, at meetings of the Academy. See Chapter I. 2.

CHAPTER III.

Of Nominations of Officers.

1. At the stated meeting in March, the President shall appoint from the next retiring Councillors a Nominating Committee of three Fellows, one for each class.

2. It shall be the duty of this Nominating Committee to prepare a list of candidates for the offices of President, Vice-Presidents, Corresponding Secretary, Recording Secretary, Treasurer, Librarian, Councillors, and the Standing Committees which are chosen by ballot; and to cause this list to be sent by mail to all the Resident Fellows of the Academy not later than four weeks before the Annual Meeting.

3. Independent nominations for any office, signed by at least five Resident Fellows and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call for the Annual Meeting, which shall then be issued not later than one week before that meeting.

4. The Recording Secretary shall prepare for use, in voting at the Annual Meeting, a ballot containing the names of all persons nominated for office under the conditions given above.

5. When an office is to be filled at any other time than at the Annual Meeting, the President shall appoint a Nominating Committee, in accordance with the provisions of Section 1, which shall announce its nomination in the manner prescribed in Section 2 at least two weeks before the time of election. Independent nominations, signed by at least five Resident Fellows and received by the Recording Secretary not later than one week before the meeting for election, shall be inserted in the call for that meeting.

CHAPTER IV.

Of the President.

1. It shall be the duty of the President, and, in his absence, of the senior Vice-President present, or next officer in order as above enumerated, to preside at the meetings of the Academy; to summon extraordinary meetings, upon any urgent occasion; and to execute or see to the execution of the Statutes of the

Academy. Length of continuous membership in the Academy shall determine the seniority of the Vice-Presidents.

2. The President, or, in his absence, the next officer as above enumerated, is empowered to draw upon the Treasurer for such sums of money as the Academy shall direct. Bills presented on account of the Library, or the Publications of the Academy, must be previously approved by the respective committees on these departments.

3. The President, or, in his absence, the next officer as above enumerated, shall nominate members to serve on the different committees of the Academy which are not chosen by ballot.

4. Any deed or writing to which the common seal is to be affixed shall be signed and sealed by the President, when thereto authorized by the Academy.

CHAPTER V.

Of Standing Committees.

1. At the Annual Meeting there shall be chosen the following Standing Committees, to serve for the year ensuing, viz.: —

2. The Committee of Finance, to consist of the President, Treasurer, and one Fellow chosen by ballot, who shall have charge of the investment and management of the funds and trusts of the Academy. The general appropriations for the expenditures of the Academy shall be moved by this Committee at the Annual Meeting, and all special appropriations from the general and publication funds shall be referred to or proposed by this Committee.

3. The Rumford Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications and claims for the Rumford Premium, also on all appropriations from the income of the Rumford Fund, and generally see to the due and proper execution of this trust.

4. The C. M. Warren Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications for appropriations from the income of the C. M. Warren Fund, and generally see to the due and proper execution of this trust.

5. The Committee of Publication, of three Fellows, to whom all memoirs submitted to the Academy shall be referred, and to

whom the printing of memoirs accepted for publication shall be intrusted.

6. The Committee on the Library, of three Fellows, who shall examine the Library, and make an annual report on its condition and management.

7. An Auditing Committee, of two Fellows, for auditing the accounts of the Treasurer.

CHAPTER VI.

OF THE SECRETARIES.

1. The Corresponding Secretary shall conduct the correspondence of the Academy, recording or making an entry of all letters written in its name, and preserving on file all letters which are received; and at each meeting he shall present the letters which have been addressed to the Academy since the last meeting. With the advice and consent of the President, he may effect exchanges with other scientific associations, and also distribute copies of the publications of the Academy among the Associate Fellows and Foreign Honorary Members, as shall be deemed expedient; making a report of his proceedings at the Annual Meeting. Under the direction of the Council for Nomination, he shall keep a list of the Fellows, Associate Fellows, and Foreign Honorary Members, arranged in their Classes and in Sections in respect to the special sciences in which they are severally proficient; and he shall act as secretary to the Council.

2. The Recording Secretary shall have charge of the Charter and Statute-book, journals, and all literary papers belonging to the Academy. He shall record the proceedings of the Academy at its meetings; and after each meeting is duly opened, he shall read the record of the preceding meeting. He shall notify the meetings of the Academy, and apprise committees of their appointment. He shall post up in the Hall a list of the persons nominated for election into the Academy; and when any individual is chosen, he shall insert in the record the names of the Fellows by whom he was nominated.

3. The two Secretaries, with the Chairman of the Committee of Publication, shall have authority to publish such of the proceedings of the Academy as as may seem to them calculated to promote the interests of science.

CHAPTER VII.

Of the Treasurer.

1. The Treasurer shall give such security for the trust reposed in him as the Academy shall require.

2. He shall receive officially all moneys due or payable, and all bequests or donations made to the Academy, and by order of the President or presiding officer shall pay such sums as the Academy may direct. He shall keep an account of all receipts and expenditures; shall submit his accounts to the Auditing Committee; and shall report the same at the expiration of his term of office.

3. The Treasurer shall keep a separate account of the income and appropriation of the Rumford Fund, and report the same annually.

4. All moneys which there shall not be present occasion to expend shall be invested by the Treasurer, under the direction of the Finance Committee, on such securities as the Academy shall direct.

CHAPTER VIII.

Of the Librarian and Library.

1. It shall be the duty of the Librarian to take charge of the books, to keep a correct catalogue of same, and to provide for the delivery of books from the Library. He shall also have the custody of the publications of the Academy.

2. The Librarian, in conjunction with the Committee on the Library, shall have authority to expend, as they may deem expedient, such sums as may be appropriated, either from the Rumford or the General Fund of the Academy, for the purchase of books, and for defraying other necessary expenses connected with the Library. They shall have authority to propose rules and regulations concerning the circulation, return, and safe-keeping of books; and to appoint such agents for these purposes as they may think necessary.

3. To all books in the Library procured from the income of the Rumford Fund, the Librarian shall cause a stamp or label to be affixed, expressing the fact that they were so procured.

4. Every person who takes a book from the Library shall give a receipt for the same to the Librarian or his assistant.

5. Every book shall be returned in good order, regard being had to the necessary wear of the book with good usage. And if any book shall be lost or injured, the person to whom it stands charged shall replace it by a new volume or set, if it belongs to a set, or pay the current price of the volume or set to the Librarian; and thereupon the remainder of the set, if the volume belonged to a set, shall be delivered to the person so paying for the same.

6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

CHAPTER IX.

Of Meetings.

1. There shall be annually four stated meetings of the Academy; namely, on the second Wednesday in May (the Annual Meeting), on the second Wednesday in October, on the second Wednesday in January, and on the second Wednesday in March. At these meetings only, or at meetings adjourned from these and regularly notified, shall appropriations of money be made, or alterations of the statutes or standing votes of the Academy be effected.

2. Fifteen Fellows shall constitute a quorum for the transaction of business at a stated meeting. Seven Fellows shall be sufficient to constitute a meeting for scientific communications and discussions.

3. The Recording Secretary shall notify the meetings of the Academy to each Fellow residing in Boston and the vicinity; and he may cause the meetings to be advertised, whenever he deems such further notice to be needful.

CHAPTER X.

OF THE ELECTION OF FELLOWS AND HONORARY MEMBERS.

1. Elections shall be made by ballot, and only at stated meetings.

2. Candidates for election as Resident Fellows must be proposed by two or more Resident Fellows, in a recommendation signed by them, specifying the Section to which the nomination is made, which recommendation shall be transmitted to the Corresponding Secretary, and by him referred to the Council for Nomination. No person recommended shall be reported by the Council as a candidate for election, unless he shall have received a written approval, signed at a meeting of the Council by at least seven of its members. All nominations thus approved shall be read to the Academy at a stated meeting, and shall then stand on the nomination list during the interval between two stated meetings, and until the balloting. No person shall be elected a Resident Fellow, unless he shall have been resident in this Commonwealth one year next preceding his election. If any person elected a Resident Fellow shall neglect for one year to pay his admission fee, his election shall be void; and if any Resident Fellow shall neglect to pay his annual assessments for two years, provided that his attention shall have been called to this article, he shall be deemed to have abandoned his Fellowship; but it shall be in the power of the Treasurer, with the consent of the Council, to dispense (*sub silentio*) with the payment both of the admission fee and of the assessments, whenever in any special instance he shall think it advisable so to do.

3. The nomination of Associate Fellows shall take place in the manner prescribed in reference to Resident Fellows; and after such nomination shall have been publicly read at a stated meeting previous to that when the balloting takes place, it shall be referred to the Council for Nomination; and a written approval, authorized and signed at a meeting of said Council by at least seven of its members, shall be requisite to entitle the candidate to be balloted for. The Council may in like manner originate nominations of Associate Fellows, which must be read at a stated meeting previous to the election, and be exposed on the nomination list during the interval.

4. Foreign Honorary Members shall be chosen only after a nomination made at a meeting of the Council, signed at the time by at least seven of its members, and read at a stated meeting previous to that on which the balloting takes place.

5. Three fourths of the ballots cast must be affirmative, and the number of affirmative ballots must amount to eleven to effect an election of Fellows or Foreign Honorary Members.

6. Each Section of the Academy is empowered to present lists of persons deemed best qualified to fill vacancies occurring in the number of Foreign Honorary Members or Associate Fellows allotted to it; and such lists, after being read at a stated meeting, shall be referred to the Council for Nomination.

7. If, in the opinion of a majority of the entire Council, any Fellow — Resident or Associate — shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his Fellowship; and provided that a majority of two thirds of the Fellows at a stated meeting, consisting of not less than fifty Fellows, shall adopt this recommendation, his name shall be stricken off the roll of Fellows.

CHAPTER XI.

Of Amendments of the Statutes.

1. All proposed alterations of the Statutes, or additions to them, shall be referred to a committee, and, on their report at a subsequent meeting, shall require for enactment a majority of two thirds of the members present, and at least eighteen affirmative votes.

2. Standing Votes may be passed, amended, or rescinded, at any stated meeting, by a majority of two thirds of the members present. They may be suspended by a unanimous vote.

CHAPTER XII.

Of Literary Performances.

1. The Academy will not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its publications.

STANDING VOTES.

1. Communications of which notice had been given to the Secretary shall take precedence of those not so notified.

2. Resident Fellows who have paid all fees and dues chargeable to them are entitled to receive one copy of each volume or article printed by the Academy, on application to the Librarian personally or by written order, within two years from the date of publication. And the current issues of the Proceedings shall be supplied, when ready for publication, free of charge, to all the Fellows and members of the Academy who desire to receive them.

3. The Committee of Publication shall fix from time to time the price at which the publications of the Academy may be sold. But members may be supplied at half this price with volumes which they are not entitled to receive free, and which are needed to complete their sets.

4. Two hundred extra copies of each paper accepted for publication in the Memoirs or Proceedings of the Academy shall be placed at the disposal of the author, free of charge.

5. Resident Fellows may borrow and have out from the Library six volumes at any one time, and may retain the same for three months, and no longer.

6. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

7. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy, except by special leave of the Librarian.

8. Books, publications, or apparatus shall be procured from the income of the Rumford Fund only on the certificate of the Rumford Committee that they, in their opinion, will best facilitate and encourage the making of discoveries and improvements which may merit the Rumford Premium.

9. The Annual Meeting and the other stated meetings shall be holden at eight o'clock, P. M.

10. A meeting for receiving and discussing scientific communications may be held on the second Wednesday of each month not appointed for stated meetings, excepting July, August, and September.

RUMFORD PREMIUM.

In conformity with the terms of the gift of Benjamin, Count Rumford, granting a certain fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of said fund, as it now exists, at any Annual Meeting, an award of a gold and silver medal, being together of the intrinsic value of three hundred dollars, as a premium to the author of any important discovery or useful improvement in light or in heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference being always given to such discoveries as shall, in the opinion of the Academy, tend most to promote the good of mankind; and to add to such medals, as a further premium for such discovery and improvement, if the Academy see fit so to do, a sum of money not exceeding three hundred dollars.

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